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## Foreword

This ETSI Technical Report (ETR) has been prepared by the Radio Equipment and Systems (RES) Technical Committee of the European Telecommunications Standards Institute (ETSI).

ETRs are informative documents resulting from ETSI studies which are not appropriate for European Telecommunication Standard (ETS) or Interim European Telecommunication Standard (I-ETS) status. An ETR may be used to publish material which is either of an informative nature, relating to the use or application of ETSs or I-ETSs, or which is immature and not yet suitable for formal adoption as an ETS or I-ETS.

## Introduction

This ETR has been written to clarify the many problems associated with the interpretation, calculation and application of measurement uncertainty.

This ETR is intended to provide, for the relevant standards, the method of calculating the measurement uncertainty relating to type testing. The report does not replace any test methods although Clause 5 contains brief descriptions of each measurement.

This ETR is intended for use, in particular, by accredited test laboratories performing type testing.

The basic purpose of this ETR is to:

- provide the method of calculating the total measurement uncertainty;
- provide the maximum acceptable "window" of measurement uncertainty ( see table A.1 in Annex A), when calculated using the methods described in this ETR;
- provide the equipment under test dependency functions (see table C.1 in Annex C) which shall be used in the calculations unless these functions are evaluated by the individual laboratories;
- provide a recommended method of applying the uncertainties in the interpretation of the results (see Annex B).

Exact measurement of a quantity which can vary infinitesimally is an ideal which cannot be attained in practical work. Both science and industry assesses measurements which are always in error by an amount that may or may not be significant for the particular purpose in hand. Examples of such errors are:

- a) that the measured value will be influenced by the operators, perhaps in a scale being misread;
- b) the test configuration or test method, which may result in the measured value being biased in some way;
- c) the test equipment used, which may be subject to several sources of error and may alter the value being measured simply by making the measurement (e.g.loading);
- d) the environment, for example the humidity and the temperature;
- e) the equipment under tests input and output impedances, transfer characteristics, stability etc.

A method is required to calculate the error of the measured value which takes into account:

- systematic errors, which are those errors inherent in the construction and calibration of the equipment used and in the method employed,
- random errors, which are errors due to chance events which, on average, are as likely to occur as not to occur and are outside the engineers control, and,
- influence quantity errors, whose magnitude is dependant on a particular parameter or function of the equipment under test (EUT).

Error is usually taken to mean the difference between the measured value of a quantity and the true value. The error is something that can never be known exactly, generally the measurement would not be made if the true value were known.

The definition of absolute error is :

Absolute error = the measured value - the true value.

The true value (which is the ideal result) is not known, only the measured value, therefore the magnitude of the absolute error can never be known, and it is only possible to approximate the true value.

To estimate the amount of error in the approximation, a set of rules is needed to apply in determining the value of the error.

In practice there usually is some idea of the size of the error inherent in the components of a system. No measuring equipment is perfect, so skill must be exercised in measurement and in the use of statistics to assess the probable limits of error, or the uncertainty. One method is by arithmetic summation, this method can be used to arrive at a range of values within which the result lies.

When, in a particular measurement system, the measured result is biased away from the true value, the mean value towards which several readings tend, is in error by a specific offset value. For example, when measuring RF power, the radio frequency attenuation of a connecting cable will consistently produce readings that are lower than the true value. The results are in error by the value of the RF attenuation of the cable.

This offset is a systematic error and if the attenuation is known the results can be corrected to eliminate this error.

Systematic errors are inherent in the construction and calibration of the equipment used and in the method employed. They cannot be measured by repeating the measurement under standard conditions.

The assessment of systematic uncertainty requires changes to be made to the measurement system. If, at the same laboratory using the same test configuration and the same test equipment, including the

set up and breakdown of the test equipment, a measurement is repeated a number of times, assuming there is a sufficient resolution in the measurement system, the measured value will differ from one measurement to the next. This is known as repeatability and corresponds to random uncertainty. The mean value of the measurements will however converge to a particular value.

Random uncertainty can only be assessed if the measurement system is sufficiently sensitive and in a state of statistical control.

If unknown variations are occurring, the mean value of the measurement will drift and will not converge to any particular value making the exercise pointless.

The assessment of random errors requires that no changes will be made to the measurement system.

The measured value that differs from one measurement to another (assuming there is sufficient resolution) by using a different test equipment configuration, or different test equipment, or by comparison with another laboratory is known as reproducibility and should not be confused with repeatability.

A further uncertainty in the measurement process is the influence from quantities which are not directly related to the function or parameter being measured. These are known as influence quantities.

Influence quantities create errors whose magnitude is dependant on a specific parameter or function of the particular equipment under test and will vary between identically built standard equipments.

The influence functions have no connection with the test equipment, they do not change the random or systematic error of the measurement system but they do interact with the measurement system to produce influence uncertainties. For example, consider the heating effect of a continuous carrier on the output stage of a power amplifier in a transmitter. Assume the measurement system would measure carrier power to within 0,5 dB, but that the transmitter output power fell at the rate of 1,0 dB per minute. If the carrier power was measured at the instant of stabilising at full power (say less than one second after switching on) a particular value for the carrier power would be recorded. If however the measurement was performed two minutes after the switching on, then the carrier power would have been 2 dB lower than that found during the first case. Both have been measured with an accuracy of 0,5 dB but the results are in fact separated by 2 dB, and have an apparent conflict as the uncertainties of both measurements do not overlap.

As the time between turning on the transmitter and the measurement is not known exactly, this is an example of an influence uncertainty and, taken to its logical conclusion, does not satisfy the requirements of estimating for a random uncertainty as it is obvious that the mean of a series of measurements will not converge but will drift to zero or until the transmitter is destroyed.

Influence uncertainty is related to the parameters of the equipment under test for example the input and output impedances, transfer characteristics, stability, sensitivity to changes in the environment etc. The dependencies can be evaluated for each equipment by the laboratories, or can be taken from table C.1 of this ETR. However arrived at, the magnitudes of the influence uncertainties shall be included in the calculation of the total uncertainty for each measurement.

When estimating the measurement uncertainty by arithmetic summation, a pessimistic range of uncertainty limits are calculated. This is because the principle of summation corresponds to the case when all the error components act in the same direction at the same time. This approach gives the maximum and minimum error bounds with 100% confidence.

To overcome this very pessimistic view of the uncertainty of measurement, the guidelines given in the reference documents have been adopted in this ETR.

These guidelines apply statistical analysis to the calculation of the overall probable error but relies on the knowledge of the magnitude and the distribution of the individual error components.

As a first principle, the following guidelines for reducing and estimating uncertainties in measurement should be used:

- a) list the sources of error that could exist in the system;
- b) separate the list into three parts: errors that are systematic errors, random (repeatability) errors, and human errors; some of the sources may appear in more than one list;
- c) examine carefully the procedure for reducing the probability of human errors (a typical one might be wrongly interpreting the manufacturers data); good documentation of results is essential;
- d) make a first estimate of the uncertainties of the systematic errors; determine the distribution factors used in the combination and arrange the lists of systematic and random errors in order of importance;

- e) consider the benefits of making a correction to a systematic error in order to reduce the systematic uncertainty, in some cases a systematic error correction may not be feasible;
- f) where corrections have been made, revise the list for systematic uncertainties;
- g) investigate repeatability; use previous experience to decide on how many samples must be made; the decision will depend, in part, on the relative size of the random errors and their distribution factors;
- h) consider tightening the control of influence quantities; you must first make an assessment of the effect of each influence quantity; there is no point in making a negligible uncertainty even smaller, or in controlling an influence quantity which has very little, if any, effect on the measured quantity;
- i) state clearly and explicitly all the assumptions in your calculations of uncertainty.

For further reading see the bibliography in Annex E.

The main advantage of this ETR is in the flexible approach that has been adopted; it is based on an "error budget" for each test. The budget is used to calculate the measurement uncertainty, which should be compared to the relevant figure in table A.1. The values in table A.1 have been set and should not be exceeded, but it is left to the individual as to how this is actually accomplished. More accurate test equipment will enable a more flexible approach whilst still remaining within the appropriate value, but it does not automatically exclude "less accurate" test equipment.

For this reason individual test equipment parameters are not specified. However, a test equipment performance for a specific parameter must be known, and including this value in the specific example will allow rapid assessment of the suitability for that particular task in relation to the other parameters. When selecting equipment that is suitable for making a particular measurement some points that should be taken into account are:

- a) the test equipment measurement uncertainty is appropriate to the required uncertainty;
- b) equipment resolution is appropriate to its uncertainty;
- c) the overall measurement uncertainty is equal to, or better than that required by the appropriate standard;
- d) equipment resolution is at least an order of magnitude better than the limits of measurement variation;
- e) the number of measurements (n) should ideally be large enough so that the measurement (n+1) varies the mean value by less than the equipment resolution or one tenth of the maximum acceptable uncertainty stated by the specification.

Caution should be exercised when:

- a) the measured parameter varies significantly from one measurement to the next;
- b) the measurement system contains loose connections, poor loads, VSWR's or conditions which vary during the measurement.

Summarising, if the uncertainty (or error bound) of a particular parameter of an item of test equipment is known, and if its interaction within a test configuration is understood, the overall measurement error can be predicted by calculation and hence controlled.

Caution should be exercised in using calibration curves or figures.

For example a particular manufacturer states an insertion loss of  $6,0 \pm 2$  dB.



The calibration curve states  $6,5 \text{ dB} \pm 0,5 \text{ dB}$  and the calibration curve figures are used in the calculation.

Subsequently, the previous three calibration reports (6 months interval) should be viewed which gives insertion losses as  $6,5 \text{ dB} \pm 0,25 \text{ dB}$ ,  $4,9 \text{ dB} \pm 0,25 \text{ dB}$  and  $7,2 \text{ dB} \pm 0,25 \text{ dB}$  respectively. Obviously this equipment has insufficient stability to allow the uncertainty of  $\pm 0,25 \text{ dB}$  to be used.

As a conclusion, calibration curves shall not be used unless they can be supported by historical evidence of the stability of the device.

This ETR has been produced, (and is to be used in conjunction with the appropriate standard, that calls up this ETR), to reconcile not only the foregoing but also the interpretation of the various elements that are required in assessing measurement uncertainty.

This will ensure that there is a clear and harmonised approach to the assessment of measurement uncertainty.

On a final note it should be remembered that no matter how carefully a measurement is made, if the equipment under test is unrepresentative, the result will also be unrepresentative. Generally the equipment under test is a sample of one from an undefined population size and is subject to unknown statistical fluctuations.

The definitions, symbols and abbreviations used in this report are described in Clause 2. This was included to ensure that there shall be no other interpretation of their meaning. Measurement equipment requirements are detailed in Clause 3.

Particular attention is drawn to subclause 4.1 which provides a general introduction to the calculation of measurement uncertainty, and includes details of some of the assumptions made and expansion of some of the definitions. Subclause 4.2 details specific examples.

A set of worked examples is included in Clause 5.

References given in this ETR can be found in Annex D.

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## 1 Scope

This document provides a method to be applied to all the applicable standards and ETRs, and supports ETSI Technical Report (ETR) 027 [1] ("Methods of measurement for mobile radio equipment").

The following aspects relate to the measurements:

- a) the calculation of the total uncertainty for each of the measured parameters;
- b) recommended maximum acceptable uncertainties for each of the measured parameters;
- c) a method of applying the uncertainties in the interpretation of the results.

This document provides the methods of evaluating and calculating the measurement uncertainties and the required corrections on measurement conditions and results. These corrections are necessary in order to remove the errors caused by certain deviations of the test system due to its known characteristics (such as the RF signal path attenuation and mismatch loss, etc).

## 2 Definitions, symbols and abbreviations

### 2.1 Definitions

For the purpose of this ETR the following definitions apply.

**Measurand:** a quantity subjected to measurement.

**Accuracy of measurement:** the closeness of the agreement between the result of a measurement and the true value of the measurand.

**Repeatability of measurements:** the closeness of the agreement between the results of successive measurements of the same measurand carried out subject to all the following conditions:

- the same method of measurement;
- the same observer;
- the same measuring instrument;
- the same location;
- the same conditions of use;
- repetition over a short period of time.

**Reproducibility of measurements:** the closeness of agreement between the results of measurements of the same measurand, where the individual measurements are carried out changing conditions such as:

- method of measurement;
- observer;
- measuring instrument;
- location;
- conditions of use;
- time.

**Uncertainty of measurement:** an estimate characterising the range of values within which the true value of a measurand lies.

**(Absolute) error of measurement:** the result of a measurement minus the (conventional) true value of the measurand.

**Random error:** a component of the error of measurement which, in the course of a number of measurements of the same measurand, varies in an unpredictable way.

**Systematic error:** a component of the error of measurement which, in the course of a number of measurements of the same measurand remains constant or varies in a predictable way.

A systematic error is unchanged when a measurement is repeated under the same conditions, but it may become evident whenever the test configuration is changed. Thus, before a systematic error can be determined and afterwards corrected, it must be identified; that is, related to some part of the measurement apparatus or procedure. Then, a modification of the method or the apparatus can be made that will reveal the error, so that a correction can be applied. Often, it is not possible to determine a systematic error precisely. In these cases a systematic uncertainty is estimated.

An example of systematic error is the cable loss which can be measured at the relevant frequencies and allowed for in the measurements. Thus a signal generator output may be set 1 dB higher than the required level, if the connecting cable loss is known to be 1 dB.

However the error in measuring the cable loss must be allowed for.

**Correction:** the value which, added algebraically to the uncorrected result of a measurement, compensates for assumed systematic error.

**Correction factor:** the numerical factor by which the uncorrected result of a measurement is multiplied to compensate for an assumed systematic error.

**Measuring system:** a complete set of measuring instruments and other equipment assembled to carry out a specified measurement task.

**Accuracy of a measuring instrument:** the ability of a measuring instrument to give indications approaching the true value of a measurand.

**Limits of error of a measuring instrument:** the extreme values of an error permitted by specifications, regulations etc. for a given measuring instrument. (This term is also known as "tolerance").

**Error of a measuring instrument:** the indication of a measuring instrument minus the (conventional) true value.

**Standard deviation of a single measurement in a series of measurements:** the parameter characterising the dispersion of the result obtained in a series of n measurements of the same measured quantity, given by the formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$

$x_i$  being the  $i$ th result of measurement ( $i = 1, 2, 3, \dots, n$ ) and  $\bar{x}$  the arithmetic mean of the n results considered.

**Standard deviation of the arithmetic mean of a series of measurements:** the parameter characterising the dispersion of the arithmetic mean of a series of independent measurements of the same value of a measured quantity, given by the formula:

$$\sigma_r = \frac{\sigma}{\sqrt{n}}$$

where  $\sigma$  is an estimate of the standard deviation of a single measurement of the series and  $n$  the number of measurements in the series.

**Confidence level:** the probability of the accumulated error of a measurement being within the stated range of uncertainty of measurement.

**Range of uncertainty (confidence interval) of measurement:** the value expressed by the formula  $2 \cdot k \cdot \sigma$  for a single measurement and by  $2 \cdot k \cdot \sigma_r$  for the arithmetic mean of a series of measurements. This corresponds to the statistical term "confidence interval". (In this document the range of uncertainty is expressed as  $\pm U_x$ ).

**Stochastic (random) variable:** a variable whose value is not exactly known, but is characterised by a distribution or probability function, or a mean value and a standard deviation (e.g. a measurand and the related measurement uncertainty).

**Quantity (measurable):** an attribute of a phenomenon or a body which may be distinguished qualitatively and determined quantitatively.

**Influence quantity:** a quantity which is not the subject of the measurement but which influences the value of the quantity to be measured or the indications of the measuring instrument or the value of the material measure reproducing the quantity.

**Influence function:** a function defining the influence of the "influence quantity" on the measurand.

Noise gradient of EUT: a function characterising the relation between an RF input signal level and SINAD of an AF output signal from the EUT.

## 2.2 Symbols

k:	a factor from Student's t distribution
$M_{iu}$ :	Mismatch uncertainty
$R_g$ :	Reflection coefficient of the generator part of a connection
$R_l$ :	Reflection coefficient of the load part of the connection
$\sigma$ :	standard deviation
$\sigma_n$ :	the standard deviation of the n'th part uncertainty
$\sigma_r$ :	the standard deviation of the mean value of a series of measurements
$\sigma_t$ :	the standard deviation of the total accumulated error
$\sigma_{n\pm}$ :	if the standard deviation consists of two figures (one for the positive (or upper) part of the uncertainty and one for the negative (or lower) part the abbreviation has a sign: For example the standard deviation of the 5 part uncertainty is characterised by two figures: $\sigma_{5+}$ and $\sigma_{5-}$ .
$U_x$ :	the uncertainty figure for the accumulated uncertainty corresponding to a confidence level of x %: $U_x = k \cdot \sigma_t$

## 2.3 Abbreviations

a:	assumed
AF:	Audio Frequency
BIPM:	the International Bureau of Weights and Measures (Bureau International des Poids et Mesures)
c:	calculated on the basis of given and measured data
d:	derived from a measuring equipment specification
EUT:	Equipment Under Test
m:	measured
p:	power level value
r:	indicates rectangular distribution
RF:	Radio Frequency
RSS:	Root-Sum-of-the-Squares
t:	indicates triangular distribution
u:	indicates U-distribution
VSWR:	Voltage Standing Wave Ratio.

## 3 General requirements

### 3.1 Test environment

Measuring equipment shall not be operated outside the manufacturer's stated temperature and humidity range.

### 3.2 Calibration

Measuring instruments and their associated components shall be calibrated by an accredited calibration laboratory.

## 4 Calculation of measurement uncertainty.

### 4.1 General

The method of calculating the total uncertainty of a measurement is to calculate the standard deviation for the distribution of the accumulated error. This method is known as the BIPM-method proposed by the International Bureau of Weight and Measures.

It is assumed, that all errors are stochastic and the total error is Gaussian distributed. (This is correct, when the total error is a combination of many individual errors, where the individual errors are not necessarily Gaussian distributed). Therefore it is possible to calculate the measurement uncertainty for a given confidence level. Calculating the standard deviation of the accumulated error is achieved by combining the standard deviations of the individual errors that contribute to the measurement uncertainty. Therefore the distribution functions of the individual errors must be known or assumed.

The standard deviation for the total accumulated error distribution corresponds to a confidence level of 68 %. It is then possible by means of Student's t function to calculate the measurement uncertainty for other confidence levels.

Both the standard deviation and Student's t factor and the confidence level shall be stated in the test report to make it possible for the user of the measured results to calculate other uncertainty figures corresponding to other confidence levels.

#### 4.1.1 The confidence level

Given that the distribution function of the accumulated error is a Gaussian function, the confidence level corresponding to the standard deviation is 68 %.

Calculating the measurement uncertainty corresponding to greater confidence levels is done by multiplying the standard deviation by Student's t factor. For example the factor corresponding to 95 % is 1,96, 99 % is 2,58.

#### 4.1.2 Error distributions

Systematic errors are, unless the actual distribution is known, assumed to have a rectangular distribution, which means, that the error with equal possibility can be anywhere between the error limits. If the limits are  $\pm a$  the standard deviation is  $a/\sqrt{3}$  (r).

Random errors, e.g. noise, are normally Gaussian distributed. The Gaussian distribution is characterised by the standard deviation alone. This is known or calculated by means of repetitive measurements.

Mismatch errors and errors caused by temperature deviations around a mean temperature are U-distributed, which means that the error is more likely to be near the limits than to be small or zero. If the limits are  $\pm a$  the standard deviation is  $a/\sqrt{2}$  (u).

Some errors are triangularly distributed. If the limits are  $\pm a$  the standard deviation is  $a/\sqrt{6}$  (t).

All the measured results shall be corrected for known errors so that the mean value of the error is zero.

#### 4.1.3 Combining standard deviations.

The calculation of the accumulated measurement uncertainty is achieved by combining the individual standard deviations by the Root-Sum-of-the-Squares (RSS) method. This is valid under the assumption that the measurement configuration (gains, attenuations, noise, non-linearities, calibration factors) are stochastic values, and that the final result of the measurement is the arithmetic summation of these values.

$$\sigma_t = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \dots + \sigma_n^2} \quad \langle 1 \rangle$$

(When a new formula is introduced in general terms it is marked with the appropriate number in triangular brackets (<n>). Whenever there is a reference to this formula it is stated as (formula <n>)).

If not all the distributions of the part uncertainties involved are symmetrical about zero, the calculation of  $\sigma_t$  is divided in two parts: one for the positive part and one for the negative part:

$$\sigma_{t+} = \sqrt{\sigma_{1+}^2 + \sigma_{2+}^2 + \sigma_{3+}^2 + \dots + \sigma_{n+}^2}$$

$$\sigma_{t-} = \sqrt{\sigma_{1-}^2 + \sigma_{2-}^2 + \sigma_{3-}^2 + \dots + \sigma_{n-}^2}$$

where  $\sigma_t$  ( $\sigma_{t+}$ ,  $\sigma_{t-}$ ) is the standard deviation of the accumulated error and  $\sigma_1$  ( $\sigma_{1+}$ ,  $\sigma_{1-}$ ) to  $\sigma_n$  ( $\sigma_{n+}$ ,  $\sigma_{n-}$ ) are the standard deviations for all the contributing errors.

The only exception to this formula is standard deviations which are closely correlated. They must be added before they are combined with the others.

In measurements, where the result is found as a difference between two or more signals or two different levels of the same signal the uncertainty of the levels contributes separately unless there is a known correlation between the errors. (Such as two levels of the same signal generator at equal frequency in the same level range or with the same attenuator setting, in which case the contribution may be insignificant).

As the mathematics requires linear values (squaring of a term in dBs is for example not defined) all figures shall be converted to linear voltage values before the formulas are applied.

If the upper and lower limits of an error contributing to the total uncertainty turns out to be different (which is the case if the limits of error are stated as  $\pm$  a value in dB) the calculations must be carried out both for the upper and the lower limit of the total uncertainty.

For the purpose of the calculations it is assumed, that the distribution function is the same as before the conversion.

The standard deviation of the total uncertainty can then be converted from linear voltage values to dB or power terms if required.

Example 1: A part uncertainty is stated as  $\pm 3$  dB.

This must be converted to percentage by means of the following formulas:

The upper limit =  $100 * (10^{3/20} - 1) \% = + 41,25 \%$  and

The lower limit =  $100 * (10^{-3/20} - 1) \% = - 29,21 \%.$

Example 2: As uncertainty is stated as  $\pm 3$  % of the power measured by an instrument. The corresponding linear voltage values are:

the upper limit:

$$= 100 * \left( \sqrt{\left(1 + \frac{3}{100}\right)} \right) - 1\% = +1,49\%$$

and,

the lower limit:

$$= 100 * \left( \sqrt{\left(1 - \frac{3}{100}\right)} \right) - 1\% = -1,51\%$$

#### 4.1.4 Combining uncertainties of different parameters, where their influence on each other is dependant on the device under test (influence quantities)

In many measurements the uncertainties of different measurement parameters influence the uncertainty of other parameters in an unknown manner that may depend either on the characteristics of the EUT or other instrumentation characteristics or both. All tests are carried out under specified standard conditions. Some standard signals may be applied to the EUT and some output parameters may be measured or the input signals may be varied in order to obtain a standard output.



It is not possible to fully characterise test conditions, signals and measurands. Uncertainties are related to each of them. These uncertainties may be well known, but their influence on the total accumulated measurement uncertainty depends on the EUT. Uncertainties related to general test conditions:

- ambient temperature;
- the effect of cooling and heating;
- power supply voltage;
- power supply impedance;
- impedance of test equipment connectors (VSWR).

Uncertainties related to applied test signals and measured values:

- level;
- frequency;
- modulation;
- distortion;
- noise.

Uncertainties that combine and influence the test results can vary from one EUT to another.

Examples of the characteristics that can affect the calculation of the uncertainties are as follows:

- receiver noise dependency of RF input signal levels;
- impedance of input and output connectors (VSWR);
- receiver noise distribution;
- performance dependency of changes of test conditions and test signals;
- modulator limiting function e.g. maximum deviation limiting;
- system random noise.

If the appropriate value for each characteristic has not been determined, the values listed in table C.1 shall be used.

These figures are based on measurements from several equipments. They are stated as mean values associated with a standard deviation reflecting the spread from one EUT to another.

When the EUT dependent uncertainties add to the total uncertainty, the RSS method of combining the standard deviations is used, but in many calculations the EUT dependency is a function that converts uncertainty from one part of the measurement configuration to another. It is assumed that the function is linear; therefore the conversion is carried out by multiplication.

The standard deviation of the uncertainty is  $\sigma_1$ . The mean value of the factor is A and its standard deviation is  $\sigma_a$ .

The standard deviation s of the converted uncertainty is:

$$\sigma = \sqrt{\sigma_1^2 * (A^2 + \sigma_a^2)} \quad <2>$$

The standard deviation is then looked upon as any other part uncertainty and is combined with the other uncertainties by means of the RSS method.

Example:

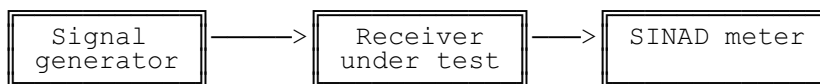


Figure 1

A receiver sensitivity measurement is to be carried out. The RF level presented to the antenna connector of the receiver has an uncertainty which is rectangularly distributed between the limits  $\pm 1$  dB from the nominal. These limits are converted into linear voltage terms: + 12,2 % and - 10,9 % corresponding to the standard deviations  $\sigma_{1+} = 7,05$  % and  $\sigma_{1-} = 6,28$  %.

The SINAD measurement is carried out with an uncertainty of a standard deviation of  $\sigma_{2+} = 7,14$  % and  $\sigma_{2-} = 6,40$  %.

The conversion factor (from table C.1) is characterised by the mean value 1,0 and the standard deviation 0,2. (Valid for both the positive and negative part of the uncertainty).

The SINAD uncertainty is then converted into RF level uncertainty ( $\sigma_3$ ) thus:

$$\sigma_{3+} = \sqrt{7,14^2 * (1,0^2 + 0,2^2)} = 7,28\%$$

$$\sigma_{3-} = \sqrt{6,40^2 * (1,0^2 + 0,2^2)} = 6,56\% \quad \text{(formular <2>)}$$

The standard deviation  $\sigma_4$  of the resulting level uncertainty is:

$$\sigma_4 = \sqrt{\sigma_1^2 + \sigma_3^2}$$

$$\sigma_{4+} = \sqrt{7,05^2 + 7,28^2} = 10,13\% \quad \text{(formular <1>)}$$

$$\sigma_{4-} = \sqrt{6,28^2 + 6,56^2} = 9,08\%$$

#### 4.1.5 Estimate of standard deviation of random errors

It is possible to estimate the standard deviation of a random error by repeating the measurement.

The first step shall be to calculate the arithmetic mean or average of the result obtained.

The spread in the measured results, i.e. the range, reflects the merit of the measurement process and depends on the apparatus used, the method, and sometimes the person making the measurement. A more useful statistic, however, is the standard deviation of the sample  $s$ . This is the root mean square different from the arithmetic mean of the sample results. If there are  $n$  results for  $x_m$  where  $m = 1, 2, \dots, n$  and the sample mean is  $\bar{x}$  then standard deviation  $\sigma$ :

$$\sigma = \sqrt{\frac{1}{n} * \sum_{m=1}^n (x_m - \bar{x})^2} \quad <3>$$

If further measurements are made, then for each sample of results considered, different values for the arithmetic mean and standard deviation will be obtained. For large values of  $n$  these mean values approach a central limit value of a distribution of all possible values. This probability density can usually be assumed, for practical purposes, to have the Gaussian form.

From the results of a relatively small number of measurements an estimate can be made of the standard deviation of the whole population of possible values, of which the measured values are a sample, from the relation.

Estimate of the standard deviation  $\sigma'$ :

$$\sigma' = \sqrt{\left(\frac{1}{n-1}\right) * \sum_{m=1}^n (x_m - \bar{x})^2} \quad <4>$$

A practical form of this formula is  $\sigma'$ :

$$\sigma' = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} \quad <5>$$

where  $X$  is the sum of the measured values and  $Y$  is the sum of the squares of the measured values.

It will be noted that the only difference between  $\sigma'$  and  $\sigma$  is in the factor  $1/(n-1)$  in place of  $1/n$ , so that the difference becomes smaller as the number of measurements is increased.

When a measured results is obtained as the arithmetic mean of a series of  $n$  measurements the standard deviation is reduced by a factor  $\sqrt{n}$  thus:

$$\sigma_r = \frac{\sigma'}{\sqrt{n}} \quad <6>$$

This is an efficient method of reducing measurement uncertainty when making noisy or fluctuating measurements, and it applies both for random errors in the measurement configuration and the EUT.

As the uncertainty due to random errors is highly dependent on the measurement configuration and the test method used it is not possible to estimate a general value.

Each laboratory must by means of repetitive measurements estimate their own standard deviations characterising the random uncertainties involved in each measurement.

Once having done this, the estimations may be used in future measurements and calculations.

**4.2 Specific to radio equipment**

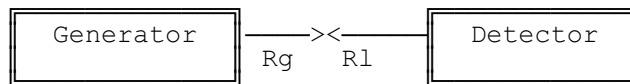
**4.2.1 Uncertainty in measuring attenuation**

In many measurements the absolute level of the RF signal is part of the measured result. The RF signal path attenuation must be known in order to apply a systematic correction to the result.

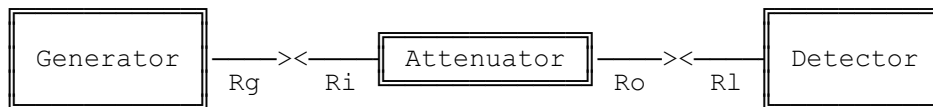
The RF signal path can be characterised using manufacturers' information about the components involved, but this method normally causes unacceptable uncertainties.

Another method is to measure the attenuation directly, for example, by using a signal generator and a detector.

To measure the attenuation, connect the signal generator to the detector and read the reference level (A) and then insert the unknown attenuation, repeat the measurement and read the new level (B).



**Figure 2: Measurement of level A**



**Figure 3: Measurement of level B**

The attenuation is calculated as B/A if the readings are linear values or A-B if the readings are in dBs.

Using this method two error sources occur. One is the linearity of the detector and the other is the mismatch uncertainties caused by reflections both at the terminals of the network under test and the instruments used.

The linearity can be obtained from the data sheets of the instruments, but the mismatch uncertainty must be estimated by calculation.

The mismatch error of the attenuation measurement can be evaluated by means of the following formula:

Error:

$$= \frac{(1 - R_g * R_l)}{1 - R_g * R_l - R_l * (R_o + R_g * (Att * Att - R_l * R_o))} \quad <7>$$

where Att is the linear value of the attenuation and  $R_g$ ,  $R_i$ ,  $R_i$ ,  $R_o$  are the complex reflection coefficients at the signal generator output, the detector input and the input and output of the unknown network (as the attenuation is not exactly known, the measured linear value B/A must be used in the calculation).

If both the magnitude and the phase of each reflection coefficient were known the error could be calculated directly and the result corrected accordingly.

But normally only the magnitudes of the reflection coefficients are known from data or from measurements so the error limits must be found from formula <7>.

When  $R_g$  and  $R_i$  are negative and  $R_i$  and  $R_o$  are positive the error is at its minimum value and when  $R_g$  and  $R_i$  are positive and  $R_i$  and  $R_o$  are negative the error is at the maximum value.

As the maximum value is slightly greater than the minimum value it is safe to consider the limits of error to be  $\pm$  the maximum value. The error distribution (found by computer simulation) of the mismatch error is close to triangular.

The standard deviation is  $a/\sqrt{6}$ , where  $\pm a$  are the limits.

The detector linearity and the mismatch uncertainty are then combined with the other errors by the normal RSS method.

Example:

an attenuator of nominal 20 dB is measured at 500 MHz by means of a signal generator and a measuring receiver. The reflection coefficient of the generator  $R_g$  is 0,2, the reflection coefficient of the measuring receiver  $R_i$  is 0,15 and the reflection coefficients of the attenuator  $R_i$  and  $R_o$  are 0,05.

The linearity uncertainty of the measuring receiver is  $\pm 0,04$  dB <d> corresponding to  $\pm 0,46$  %.

The signal generator is adjusted to 0 dBm and the reference level A is measured. (As the receiver has a ratio function A = 0 dB).

Then the attenuator is inserted and the level B = - 20,2 dB is measured.

The attenuation is then 20,2 dB. The linear value is 0,098. By means of formula <7> the error limits are found: ( $R_g = - 0,2$ ,  $R_i = - 0,05$ ,  $R_i = 0,15$  and  $R_o = 0,05$ )

Max value:

$$= \frac{(1 + 0,2 * 0,15)}{1 - 0,2 * 0,05 - 0,5 * (0,05 - 0,2 * (0,098 + 0,05 * 0,05))}$$

$$= 1,048 \text{ corresponding to limits of } \pm 4,8\%$$

The standard deviation of the total uncertainty:

$$\sigma_t = \frac{0,46^2}{3} + \frac{4,8^2}{6} = 1,98\%$$

This uncertainty can be reduced significantly by means of inserting attenuators with low reflection coefficients at the generator output and the receiver input.

If all reflection coefficients are 0,05 the corresponding uncertainty is reduced to  $\sigma_t = 0,42$  %.

**4.2.2 Mismatch uncertainty**

Where two parts or elements in a measurement configuration are connected there will be a mismatch uncertainty of the level of the RF signal passing through the connection, because the matching is not ideal. The extent of the uncertainty depends on the VSWR of the two connectors connected together.

The error limits of the mismatch uncertainty are calculated by means of the following formula:

$$M_{iu} = R_g * R_l * 100\% \tag{8}$$

where  $R_g$  and  $R_l$  are the arguments of the reflection coefficients involved in the connection between the two components. ( $R_g$  is the generator part and  $R_l$  is the load part).

The distribution of the mismatch error is U-shaped. If  $M_{iu}$  is  $\pm a$ , the standard deviation is  $a/\sqrt{2}$ .

For the calculation of mismatch uncertainty at the antenna connector of the EUT the reflection coefficient of the receiver or transmitter is required. Therefore the laboratory must either be able to measure it in advance or it must use the reflection coefficients given in table C.1.

As the reflection coefficients given in table C.1 each consist of a mean value and a standard deviation some additional calculation has to be done.

First the standard deviation from table C.1 must be normalised (divided) by the mean value. Then the uncertainty correction factor  $c$  (which is a function of the normalised standard deviation) is taken from the graph given in figure 4 in subclause 4.2.2.

Then  $M_{iu}$  is calculated by means of formula <8> (using the mean value from table C.1 and  $R_l$ ). Finally the standard deviation of the mismatch uncertainty is calculated:

$$\sigma = c * \frac{M_{iu}}{\sqrt{2}} \tag{9}$$

**Uncertainty correction factor**

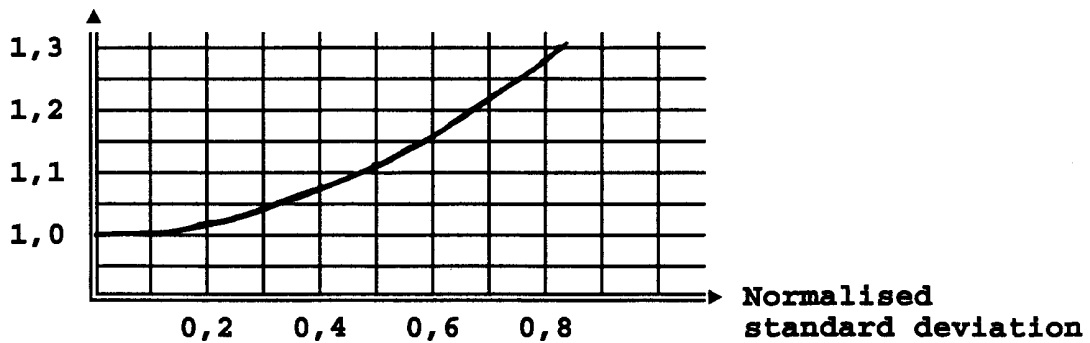


Figure 4

Example:

The mismatch uncertainty at the antenna connector when measuring the carrier power is calculated as follows:

the reflection coefficient of the input of the matching network is measured to be 0,1.

The reflection coefficient of the EUT is characterised as the mean value  $m_{\text{table C.1}} = 0,5$  and the standard deviation  $\sigma_{\text{table C.1}} = 0,2$  in table C.1.

$$M_{iu} = 0,1 * 0,5 * 100 \% = 5,0 \% \quad (\text{formula <8>})$$

$$\sigma = M_{iu} / \sqrt{2} \% = 5,0 / \sqrt{2} \% = 3,54 \%$$

$$\sigma' = \frac{\sigma_{\text{table C.1}}}{m_{\text{table C.1}}} = 0,2 / 0,5 = 0,4$$

The uncertainty correction factor is found to be 1,075 by means of the graph given in figure 4.

The st. deviation of the mismatch uncertainty:

$$\sigma_{miu} = 3,54 * 1,075 \% = 3,81 \% \quad (\text{formula <9>})$$

#### 4.2.3 Mismatch loss

Where a 50  $\Omega$  source is connected to a not ideal termination part of the power is reflected back into the source.

The amount of reflected power (the mismatch loss) depends on the reflection coefficient of the termination or load.

$$\text{Mismatch loss} = 10 * \log(1 - R_l^2) \quad <10>$$

where  $R_l$  is the argument of the reflection coefficient of load.

In measurements where the level of the RF signal is part of the measured result the RF level shall be corrected for mismatch loss. The only exception is the mismatch loss at the antenna connector of the EUT related to RF signals supplied to the EUT.

#### 4.2.4 Uncertainty in measuring third order intermodulation rejection

##### 4.2.4.1 Third order intermodulation mechanisms

When two unwanted signals X and Y occur at frequency distance  $d$  (X) and  $2 \times d$  (Y) from the receiving channel a disturbing signal Z is generated in the receiving channel due to non linearities in filters, amplifiers and mixers.

The predominant function is a third order function:

$$I_z = I_c + 2 * I_x + I_y \quad <11>$$

where  $I_z$  is the level of the intermodulation product Z,  $I_c$  is a constant,  $I_x$  and  $I_y$  are the levels of X and Y. All terms are logarithmic.

#### 4.2.4.2 The measurement of third order intermodulation rejection

Three signal generators are connected to the input of the EUT.

Generator 1 is adjusted to a specified level at the receiving frequency  $f_0$  (the wanted signal W).

Generator 2 is adjusted to frequency  $f_0+d$  (unwanted signal X) and generator 3 is adjusted to frequency  $f_0+2*d$  (unwanted signal Y). The level of X and Y ( $1_x$  and  $1_y$ ) are maintained equal during the measurement.

$I_x$  and  $I_y$  are increased to level A which causes a specified degradation of AF output signal.

The level of the wanted signal W is  $A_w$  (see figure 5 following).

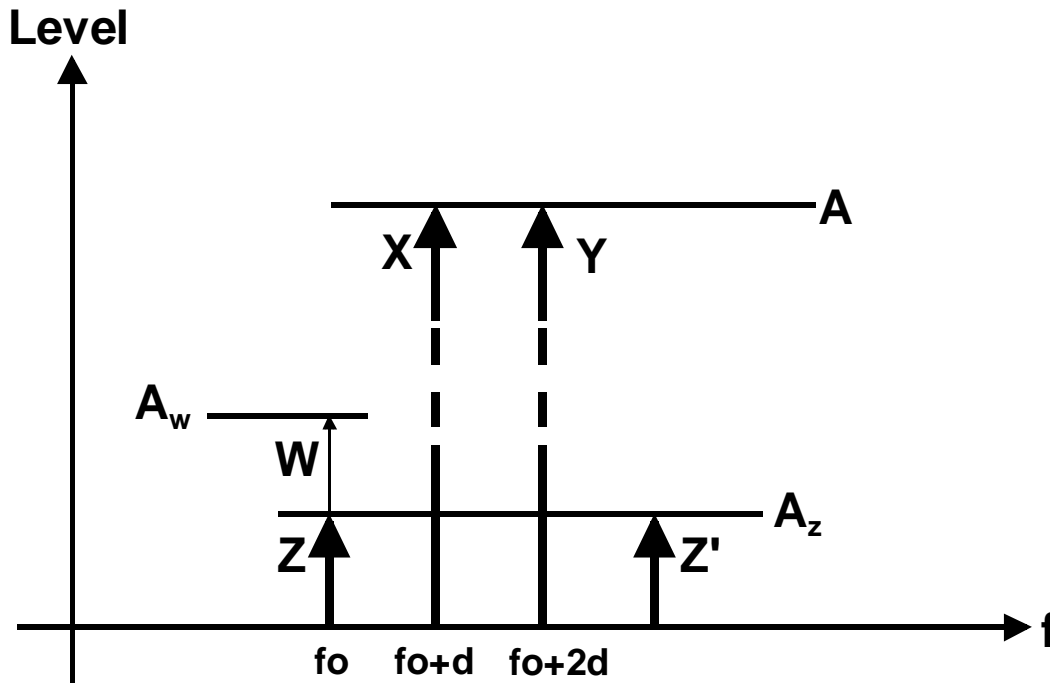


Figure 5

The measured result is the difference between the level of the wanted signal  $A_w$  and the level of the two unwanted signals A. This is the ideal measurement.

#### 4.2.4.3 Uncertainties involved in the measurement

The predominant error sources related to the measurement are the uncertainty of the levels of the applied RF signals and uncertainty of the degradation (the SINAD measurement). The problems about the SINAD uncertainty are exactly the same as those involved in the co-channel rejection measurement if the intermodulation product Z in the receiving channel is looked upon as the unwanted signal in this measurement. Therefore the noise gradient is the same, but due to the third order function the influence on the total uncertainty is reduced by a factor 3.



4.2.4.3.1 Uncertainty due to the signal level uncertainty of the two unwanted signals

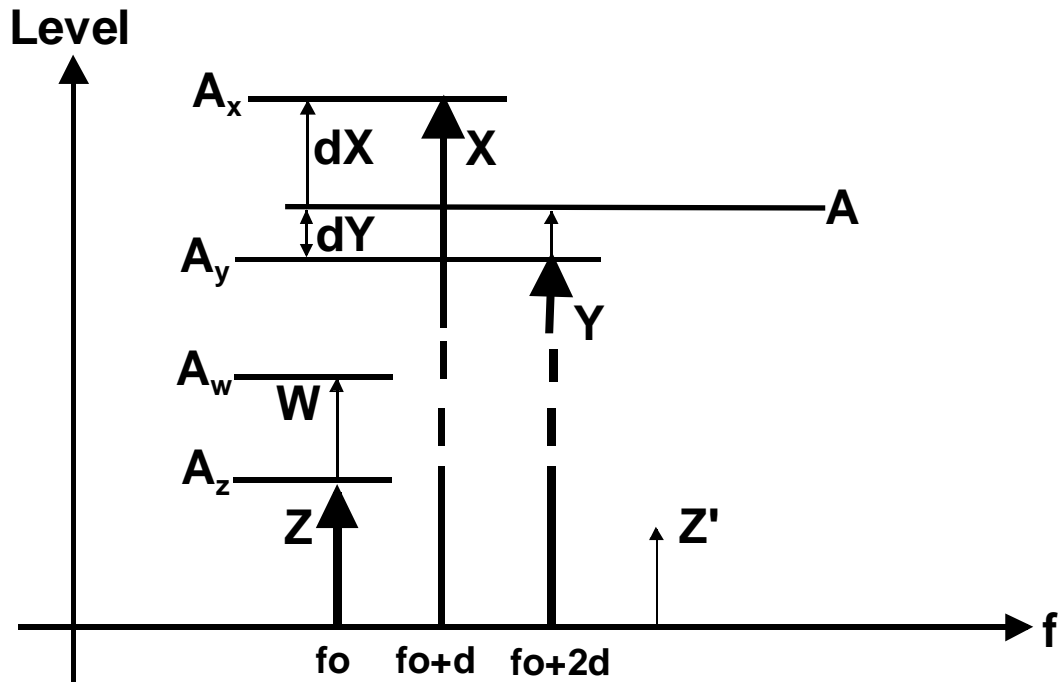


Figure 6

A is the assumed level of the two unwanted signals (the indication of the two unwanted signal generators)

$A_x$  is the true level of X and  $A_y$  is the true level of Y. ( $A_x$  is  $A+dx$  and  $A_y$  is  $A+dy$ ).  
 $A_z$  is the level of Z (the same as in the ideal measurement).

If  $A_x$  and  $A_y$  were known the correct measuring result would be obtained by adjusting the two unwanted signals to the level  $A_t$  (true value) which still caused the level  $A_z$  of Z.

A change of the level of X causes the double change of the level of Z (in dB) while a change of the level of Y causes an equal change of the level of Z.

Therefore  $A_t = A + 2 * dx/3 + dy/3$  <12>

The difference  $A_t - A$  is the error of the measurement because  $dx$  and  $dy$  are not known, so  $A$  is the value used.

When looking at the problem in linear terms, formula <12> is valid for small values of  $dx$  and  $dy$  due to the fact that the higher order components of the third order function can be neglected.

$dx$  and  $dy$  are the relative RF level errors at the input of the EUT. They are combinations of signal generator level uncertainty, matching network attenuation uncertainty and mismatch uncertainties at the inputs and the output of the matching network.

The standard deviations related to the uncertainties of the levels of X and Y are  $\sigma_x$  and  $\sigma_y$ .

The standard deviation  $\sigma_1$  related to the uncertainty caused by level uncertainty of the two unwanted signals are thus:

$$\sigma_1 = \sqrt{\left(2 * \frac{\sigma_x}{3}\right)^2 + \left(\frac{\sigma_y}{3}\right)^2} \quad <13>$$

#### 4.2.4.3.2 Error caused by signal level uncertainty of the wanted signal

Under the assumption that equal change of both the level of the wanted signal and the intermodulation product will cause no change of the SINAD, the error contribution from the uncertainty of the level of the wanted signal can be calculated:

equal change of the level of the two disturbing signals causes 3 times this change in the level of the intermodulation product (valid for small changes).

Therefore if the error of the level of the wanted signal is  $dw$ , the error contribution to the measured results is  $2/3 * dw$ .

Assuming the same types of errors as previous the standard deviation for this uncertainty  $\sigma_2$  is

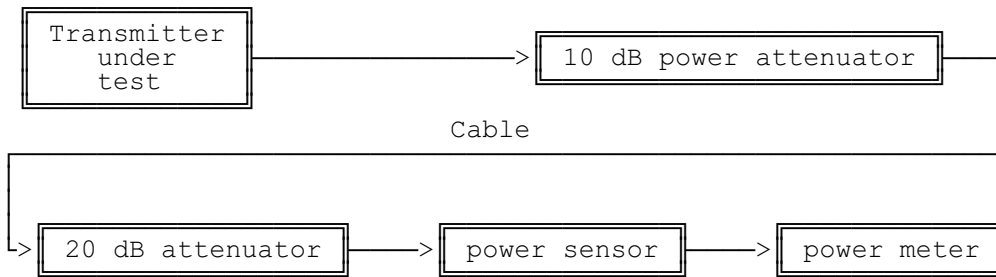
$$\sigma_2 = 2 * \sigma_w / 3 \quad <14>$$

where  $\sigma_w$  is the standard deviation of the level uncertainty of the wanted signal.

#### 4.2.4.3.3 Error caused by SINAD measurement uncertainty

Under the assumption that only the intermodulation product in the receiving channel is degrading the signal, the figures from table C.1 can be used to transform the SINAD measurement uncertainty to a level uncertainty by means of formula <2> as described in subclause 4.1.4.

**4.2.5 An example of calculation of the measurement uncertainty concerning the measurement of the transmitter carrier power**



**Figure 7: measurement configuration**

The power meter uses a thermocouple power sensor module and contains a power reference.

The attenuating network consists of two power attenuators: one of 10 dB and one of 20 dB connected by a cable. The nominal carrier power is 25 Watts, so the power level at the input of the power sensor module is said to be 25 mW.

The carrier frequency is 460 MHz.

The transmitter under test is in a temperature chamber at + 55 °C.

The transmitter is designed for continuous use.

**4.2.5.1 Power meter and sensor module uncertainty**

(Subclauses 2.2 and 2.3 refer to symbols and abbreviations used in the following calculations).

Reference level uncertainty:	(± 1,2%) (p) (d)	± 0,6% (r)
Mismatch uncertainty when calibrating: $VSWR_g = 1,05$ , $VSWR_l = 1,15 \rightarrow$ $R_g = 0,024$ and $R_l = 0,070$	(c) (d)	± 0,17% (u)
Calibration factor uncertainty	(± 2,3%) (p) (d)	± 1,14% (r)
Range to range change error (one range change)	(± 0,5%) (p) (d)	± 0,25% (r)
Meter linearity	(± 0,5%) (p) (d)	± 0,25% (r)

Noise and drift is negligible at this power level and can be ignored.

$$\sigma_1 = \sqrt{\frac{0,6^2 + 1,14^2 + 0,25^2 + 0,25^2}{3} + \frac{0,17^2}{2}} = 0,78\% \quad \text{(formula <1>)}$$

**4.2.5.2 Matching network and mismatch uncertainties**

The error sources connected with the cables and the attenuator can be derived in different ways:

Either the available data of the attenuators and cables can be used directly (Example 1) or the attenuation and reflection coefficients can be measured (Example 2).

**4.2.5.2.1 Calculations based on available data**

Attenuator uncertainty	(± 0,4 dB)	(d)	+ 4,71 / - 4,50 % (r)
Cable attenuation 0,3 dB		(m)	
Cable attenuation uncertainty ± 0,1 dB			+ 1,16 / - 1,15 % (r)

Mismatch uncertainties at the antenna connector of the transmitter:  
 (VSWR<sub>att</sub> 1,2 → R<sub>l</sub> = 0,091 and R<sub>g</sub> of the transmitter under test taken from table C.1 (Annex C):

Mean = 0,5, std. dev. = 0,2)

$$M_{iu} = 0,091 * 0,5 * 100 \% = \pm 4,55 \% \quad (u) \quad (c) \quad (\text{formula } <8>)$$

Normalised std. dev. of R<sub>g</sub> = 0,2/0,5 = 0,4

Uncertainty correction factor (taken from figure 4 in subclause 4.2.2) = 1,075

$$\text{St. dev. of mismatch uncertainty at the antenna connector} = 1,075 * 4,55 / \sqrt{2} = \quad (\text{formula } <9>) \quad \pm 3,46 \% (\sigma)$$

Mismatch uncertainty at power sensor module:

R<sub>l</sub> = 0,07 and VSWR of the cable connector is 1,3 → R<sub>g</sub> = 0,13

$$M_{iu} = 0,13 * 0,07 * 100 \% \quad (c) \quad (\text{formula } <8>) \quad \pm 0,91 \% (u)$$

$$\sigma_{2+} \sqrt{\frac{4,71^2 + 1,16^2}{3} + 3,46^2 + \frac{0,91^2}{2}} = 4,50\% (\sigma)$$

$$\sigma_{2+} \sqrt{\frac{4,50^2 + 1,15^2}{3} + 3,46^2 + \frac{0,91^2}{2}} = 4,42\% (\sigma) \quad (\text{formula } <1>)$$

#### 4.2.5.2.2 Calculations based on measured data

(The measurements carried out at 23 °C)

Measured attenuation of network: 30,5 dB

The attenuation is measured with a signal generator and a measuring receiver. At both the input and output connector a 6 dB attenuator with low reflection coefficients has been inserted (see subclause 4.2.1 about the method and the uncertainty calculation concerning the method).

Detector uncertainty 0,06 dB (d) ± 0,69 % (r)

Mismatch uncertainty:

(The reflection coefficients of the measuring system  $R_g$  and  $R_l < 0,025$  and the network reflection coefficients  $R_i$  and  $R_o < 0,1$ )

Limits = 0,6 % voltage (c) ± 0,6 % (t)

Temperature influence: 0,0001 dB/degree, which is negligible and can be ignored (d)

Power influence 0,0001 dB/dB \* Watt (10 dB attenuator):  
0,001 \* 2,5 \* 10 = 0,25 dB (d) (c) + 2,92 / - 2,84 % (r)

Power influence 0,001 dB/dB\*Watt (20 dB attenuator):  
0,001 \* 2,5 \* 20 = 0,05 dB (d) (c) + 0,58 / - 0,57 % (r)

Mismatch uncertainties at the antenna connector of the transmitter:

(VSWR<sub>att</sub> 1,2 →  $R_l = 0,091$  and  $R_g$  of the transmitter under test, taken from table C.1:

Mean = 0,5, std. dev. = 0,2)

$M_{iu} = 0,091 * 0,5 * 100 \% = \pm 4,55 \%$  (u) (c) (formula <8>)

Normalised std. dev. of  $R_g = 0,2/0,5 = 0,4$

Uncertainty correction factor (taken from the figure 4 in subclause 4.2.2) = 1,075

Std. dev. of mismatch uncertainty at the antenna connector =  $1,0750 * 4,55 / \sqrt{2} =$  (formula <9> 3,46 % ( $\sigma$ ))

Mismatch uncertainty at power sensor module: ( $R_l = 0,07$  and VSWR of the cable connector is 1,3 →  $R_g = 0,13$ )

$M_{iu} = 0,07 * 0,13 * 100$  (c) ± 0,91 % (u)

$$\sigma_{3+} = \sqrt{\frac{0,69^2 + 2,92^2 + 0,58^2}{3} + \frac{0,6^2}{6} + 3,46^2 + \frac{0,91^2}{2}} = 3,94\%$$

$$\sigma_{3-} = \sqrt{\frac{0,69^2 + 2,84^2 + 0,57^2}{3} + \frac{0,6^2}{6} + 3,46^2 + \frac{0,91^2}{2}} = 3,92\%$$

As the difference between  $\sigma_{3+}$  and  $\sigma_{3-}$  is small  $\sigma_3 = \sigma_{3+}$  will be used in the following calculation.

As can be seen, the uncertainty can be reduced by measuring the measurement configuration characteristics involved.

**4.2.5.3 Uncertainty caused by influence quantities**

Ambient temperature = 20 °C ± 1 °C (r)

Uncertainty caused by temperature uncertainty:

Dependency function (from table C.1):

Mean: 1 Watt/°C and std. dev.: 0,3 Watt/°C

The nominal carrier power is 25 Watts.

Therefore the dependency function is:

Mean: 1/25 %/°C = 4,0 %/°C and

Std. dev.: 0,3/25 %/°C = 1,2 %/°C

Standard deviation of the power uncertainty caused by ambient temperature uncertainty (formula <2>) =

$$\sqrt{(1^2 / 3) * (4,0^2 + 1,2^2)} = 2,41\% (p)(\sigma)$$

This is then transformed to voltage: 2,41/2 % = 1,21 % (σ)

Supply voltage = V<sub>set</sub> ± 100 mV (r)

Uncertainty caused by supply voltage uncertainty:

Dependency function (from table C.1):

Mean: 10 %/V and st. dev.: 3 %/V (p)

Standard deviation of the power uncertainty caused by power supply voltage uncertainty (formula <2>) =

$$\sqrt{(0,1^2 / 3) * (10^2 + 3^2)} = 0,60\%$$

This is then converted to voltage: 0,60/2 % = 0,30 % (σ)

$$\sigma_4 = \sqrt{1,21^2 + 0,30^2} = 1,25\% (\sigma)$$

**4.2.5.4 Random uncertainty**

The measurement was repeated 9 times

The following results were obtained:

21,8 mW 22,8 mW 23,0 mW 22,5 mW 22,1 mW 22,7 mW 21,7 mW 22,3 mW 22,7 mW

Mean value = 22,4 mW Standard deviation = 0,455 mW

(Calculated by means of formula <5>).

As the result is obtained as the mean value of 9 measurements the standard deviation of the random uncertainty is:

$$\sigma_5 = 100 * 0,455 / (22,4 * \sqrt{9}) \% = 0,68\% (\text{formula } <6>) (p) (\sigma)$$

This is converted to linear voltage: 0,68/2 % = 0,34 % (σ)

#### 4.2.5.5 Total uncertainty

The standard deviation of the accumulated error is then:

$$\sigma_{i(1)} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_4^2 + \sigma_5^2} :$$

$$\sigma_{i+} = \sqrt{0,78^2 + 4,50^2 + 1,25^2 + 0,34^2} = 4,75\% (\sigma)$$

$$\sigma_{i-} = \sqrt{0,78^2 + 4,42^2 + 1,25^2 + 0,34^2} = 4,67\% (\sigma)$$

$$\sigma_{i(2)} = \sqrt{\sigma_1^2 + \sigma_3^2 + \sigma_4^2 + \sigma_5^2} =$$

$$\sqrt{0,78^2 + 3,94^2 + 1,25^2 + 0,34^2} = 4,22\% (\sigma)$$

At a confidence level of 95 % the two measurement uncertainty figures are:

$$U_{95}(1) = + 1,96 * 4,75 / - 1,96 * 4,67 \% = + 9,31 / - 9,15 \%$$

$$\text{corresponding to } + 19,5 / - 17,5 \% (p) = + 0,77 / - 0,83 \text{ dB}$$

and,

$$U_{95}(2) = \pm 1,96 * 4,22 \% = \pm 8,27 \%$$

$$\text{corresponding to } + 17,2 / - 15,9 \% (p) = + 0,69 / - 0,75 \text{ dB.}$$

The mean value of the readings was 22,4 mW

This figure is then corrected with the attenuation of the matching network and the mismatch loss at input and output of the network.

Mismatch loss at input ( $R_I = 0,091$ ) = 0,036 dB and at the output ( $R_O = 0,07$ ) = 0,021 dB (formula <10>)

The total correction is then:

$$0,036 + 0,021 + 30 + 0,3 = 30,36 \text{ dB} = 1086 (1) \text{ or}$$

$$0,036 + 0,021 + 30,5 = 30,56 \text{ dB} = 1138 (2)$$

$$\text{Carrier power} = 22,4 \text{ mW} * 1086 = 24,3 \text{ Watts (Example 1)}$$

$$\text{or, } 22,4 \text{ mW} * 1138 = 25,5 \text{ Watts (Example 2)}$$

When measuring the carrier power of a transmitter designed for intermittent use there is an additional uncertainty due to the fact that the transmitter is not in thermal stability and that the time when the measurement is made, is not sufficiently defined.

The uncertainty is taken from table C.1: "Time-duty cycle dependency": 3 % (p) (r) which in both example 1 and 2 would add approximately 1 % (p) to the total uncertainty.

## 5 Examples

The following pages of Clause 5 are examples of test configurations with corrections and error sources.

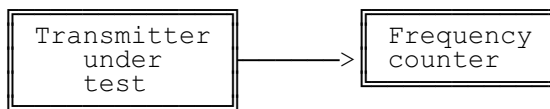
Components essential for the measurement uncertainty calculations are shown in the drawings. Influence quantities (such as supply voltage, ambient temperature) are not shown though they are (in principle) present in all the examples.

Symbols and abbreviations used in the examples are explained in subclause 2.2 and subclause 2.3.

Each example includes calculation of the measurement uncertainty at a confidence level of 95 %.

### 5.1 Transmitter measurements

#### 5.1.1 Frequency error



**Figure 8: Measurement configuration**

The signal is applied to a frequency counter through a matching network.

The frequency is read directly. The equipment is designed for intermittent use, the nominal frequency is 900 MHz and the temperature is  $25\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ .

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

the timebase of the counter used has a drift of  $1 \times 10^{-9}$  per day. With a calibration period of less than 10 days, the time base uncertainty is less than  $1 \times 10^{-8}$ .

The least significant digit is 10 Hz.

The overall uncertainty is time base uncertainty + 3 counts of least significant digit or 30 Hz whichever is larger.

The uncertainty related to the measurement of 1 GHz is then:

Time base uncertainty	(c) (d)	$\pm 10\text{ Hz (r)}$
Counter uncertainty	(d)	$\pm 30\text{ Hz (r)}$
Uncertainty due to ambient temperature uncertainty:		
Standard deviation of ambient:		
temperature uncertainty = $3/\sqrt{3} = 1,73\%$	( $\sigma$ )	

Dependency function taken from table C.1:  
 mean =  $0,02\text{ ppm}/^{\circ}\text{C} * 900\text{ MHz} = 18\text{ Hz}$   
 std. dev. =  $0,01\text{ ppm}/^{\circ}\text{C} * 900\text{ MHz} = 9\text{ Hz}$

Uncertainty due to ambient temperature:

uncertainty:

$$\sqrt{1,73^2 * (18^2 + 9^2)} = (\text{formula <2>)} \quad 35\text{ Hz } (\sigma)$$



Time-duty cycle error (taken from table C.1):

50 Hz ( $\sigma$ )

$$\sigma_t = \sqrt{\frac{(10^2 + 30^2)}{3} + 35^2 + 50^2} = 64 \text{ Hz } (\sigma)$$

$$U_{95} = \pm 1,96 * 64 \text{ Hz} = \pm 125 \text{ Hz}$$

### 5.1.2 Carrier power

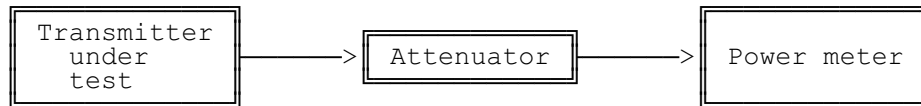


Figure 9: Measurement configuration.

The power meter is a thermocouple power sensor module and a meter with a built in power reference.

The attenuating network consists of two power attenuators : one of 10 dB and one of 20 dB connected by a cable. The nominal carrier power is 25 Watts, so the power level at the input of the power sensor module is said to be 25 mW.

The carrier frequency is 460 MHz.

The transmitter under test is in a temperature chamber at + 55 °C ± 1 °C. The equipment is designed for intermittent use.

The test configuration, the list of errors sources and the calculations are examples only and may not include all the possibilities.

It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Power meter and sensor module:

Reference level uncertainty : ( ± 1,2 % )	(p) (d)	± 0,6 % (r)
Mismatch uncertainty when calibrating (VSWR <sub>g</sub> = 1,05, VSWR <sub>l</sub> = 1,15 → R <sub>g</sub> = 0,024 and R <sub>l</sub> = 0,070) (formula <8>)	(c) (d)	± 0,17 % (u)

Calibration factor uncertainty: ( ± 2,3 % (d)(p) )		± 1,14 % (r)
---	--	--------------

Range to range change error : (one range change) ( ± 0,5 % )	(p) (d)	± 0,25 % (r)
---	---------	--------------

Meter linearity ( ± 0,5 % )	(p) (d)	± 0,25 % (r)
-----------------------------	---------	--------------

Noise and drift is negligible at this power level and can be ignored.

$$\sigma_1 = \sqrt{\frac{0,6^2 + 1,14^2 + 0,25^2 + 0,25^2}{3} + \frac{0,17^2}{2}} = 0,78 \% (\sigma)$$

Matching network and mismatch:

Detector uncertainty 0,06 dB (d) ± 0,69 % (r)

Mismatch uncertainty:

(The reflection coefficients of the measuring system  $R_g$  and  $R_l < 0,025$  and the network reflection coefficients  $R_i$  and  $R_o < 0,1$ )

Limits = 0,6 % voltage (c) (formula <7>) ± 0,6 % (t)

Temperature influence: 0,0001 dB/degree which is negligible and can be ignored.

(d)

Power influence 0,001 dB/dB\*Watt (10 dB attenuator):  
 $0,001 * 25 * 10 = 0,25$  dB

(d) (c) + 2,92 / - 2,84 % (r)

Power influence 0,001 dB/dB\*Watt (20 dB attenuator):  
 $0,001 * 2,5 * 20 = 0,05$  dB

(d) (c) + 0,58 / - 0,57 % (r)

Mismatch uncertainties at the antenna connector of the transmitter:

( $VSWR_{att} 1,2 \rightarrow R_l = 0,091$  and  $R_g$  of the transmitter under test taken from table C.1:

Mean = 0,5, std. dev. = 0,2)

$M_{iu} = 0,091 * 0,5 * 100 \% = \pm 4,55 \%$

(u) (c) (formula <8>)

Normalised std. dev. of  $R_g = 0,2/0,5 = 0,4$

Uncertainty correction factor (taken from the figure 4 in subclause 4.2.2) = 1,075

Std. dev. of mismatch uncertainty at the antenna connector =  $1,075 * 4,55/\sqrt{2} =$  (formula <9>)

3,46 % ( $\sigma$ )

Mismatch uncertainty at power sensor module: ( $R_l = 0,07$  and  $VSWR$  of the cable connector is 1,3  $\rightarrow R_g = 0,13$ )

$M_{iu} = 0,07 * 0,13 * 100$

(c) ± 0,91 % (u)

$$\sigma_{2+} = \sqrt{\frac{0,69^2 + 2,92^2 + 0,58^2}{3} + \frac{0,6^2}{6} + 3,46^2 + \frac{0,91^2}{2}} = 3,94\%$$

$$\sigma_{2-} = \sqrt{\frac{0,69^2 + 2,84^2 + 0,57^2}{3} + \frac{0,6^2}{6} + 3,46^2 + \frac{0,91^2}{2}} = 3,92\%$$

As the difference between  $\sigma_{2+}$  and  $\sigma_{2-}$  small  $\sigma_2 = \sigma_{2+}$  will be used in the following calculation.

Uncertainty due to influence quantities:

Ambient temperature =  $55 \text{ }^\circ\text{C} \pm 1 \text{ }^\circ\text{C}$

(r)

Uncertainty caused by temperature uncertainty:

Dependency function (from table C.1):

Mean : 1 Watt/ $^\circ\text{C}$  and std. dev: 0,3 Watt/ $^\circ\text{C}$

The nominal carrier power is 25 Watts. Therefore the dependency function is:

Mean :  $1/25 \% /^\circ\text{C} = 4,0 \% /^\circ\text{C}$  and

Std. dev :  $0,3/25 \% /^\circ\text{C} = 1,2 \% /^\circ\text{C}$

Standard deviation of the power uncertainty caused by ambient temperature uncertainty (formula <2>) =

$$\sqrt{(1^2 / 3) * (4,0^2 + 1,2^2)} = 2,41\% (p) (\sigma)$$

This is then converted to voltage: 2,41/2 % =

1,21 % ( $\sigma$ )

Supply voltage =  $V_{\text{set}} \pm 100 \text{ mV}$  (r)

Uncertainty caused by supply voltage uncertainty:

Dependency function (from table C.1):

Mean : 10 %/V and std. dev. 3 %/V (p)

Standard deviation of the power uncertainty caused by power supply voltage uncertainty (formula <2>) =

$$\sqrt{(0,1^2 / 3) * (10^2 + 3^2)} = 0,60\% (p) (\sigma)$$

This is then converted to voltage: 0,60/2 % =

0,30 % ( $\sigma$ )

$$\sigma_3 = \sqrt{1,21^2 + 0,30^2} =$$

1,25 % ( $\sigma$ )

Random uncertainty:

The measurement was repeated 9 times.

The following results were obtained:

21,8mW 22,8mW 23,0 mW 22,5mW 22,1mW 22,7mW 21,7mW 22,3mW 22,7mW

Mean value = 22,4 mW

Standard deviation = 0,455 mW

As the result is obtained as the mean value of 9 measurements the standard deviation of the random uncertainty is

$$\sigma_4 = 100 * 0,455 / (22,4 * \sqrt{9}) \% = 0,68 \% (p) (\sigma)$$

This is converted to linear voltage: 0,68/2 % =

0,34% ( $\sigma$ )

5 Time-duty-cycle uncertainty:

The standard deviation of the time-duty-cycle error =

2 % (p). (Taken from table C.1)

This is converted to voltage:  $\sigma_5 = 2/2 \% =$

1,0 % ( $\sigma$ )

Total uncertainty:

$$\sigma_t = \sqrt{0,78^2 + 3,94^2 + 1,25^2 + 0,34^2 + 1,0^2} = 4,34\% (\sigma)$$

$$U_{95} = \pm 1,96 * 4,34 \% = 8,50 \% = + 17,7 / - 16,3 \% (p) \Leftrightarrow + 0,71 / - 0,77 \text{ dB}$$

5.1.3 Frequency deviation

5.1.3.1 Maximum frequency deviation



Figure 10: Measurement configuration

The AF signal from the audio frequency oscillator is supplied to the modulation input of the transmitter under test d.

The RF signal is applied to a deviation meter.  
 The maximum deviation is measured to be 4,0 kHz.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities.

It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

(It is assumed that the AF level uncertainty has no influence)

Demodulator uncertainty: ± 1 % (d) (r)

± 1 digit = 10 Hz = 100 \* 10 / 4000 % ± 0,25 % (r)

Residual modulation ± 20 Hz (d) = 100 \* 20 / 4000 = ± 0,5 % (r)

$$\sigma_t = \sqrt{(1,0 + 0,25^2 + 0,5^2)} / 3 = 0,66\% (\sigma)$$

U<sub>95</sub> is ± 1,96 \* 0,66 % = ± 1,3 %

5.1.3.2 Modulation frequencies above 3 kHz

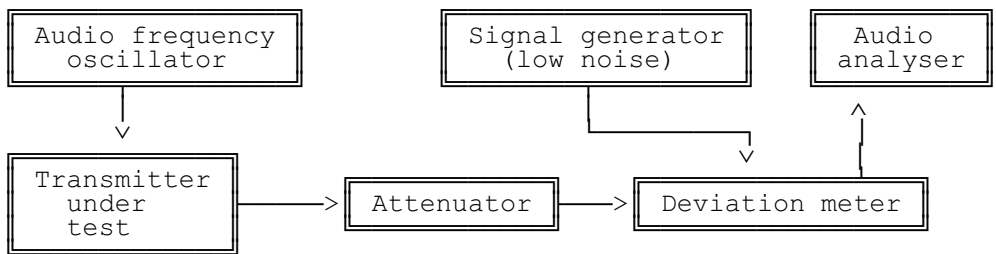


Figure 11: Measurement configuration

The AF signal from the audio frequency oscillator is supplied to the modulation input of the transmitter under test d. The RF signal is applied to a deviation meter. The demodulated signal is then applied to the audio analyser. A low noise signal generator is used as local oscillator for demodulating signals with modulation frequency beyond 3 kHz to improve the noise behaviour. The result is corrected for AF gain and AF filter shaping.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities.

It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

AF oscillator uncertainty	± 0,7 % (d)(r)
Demodulator uncertainty	± 1 % (d)(r)
AC voltmeter uncertainty	± 4 % (d)(r)
AF gain uncertainty	± 2 % (d)(r)

$$\sigma_t = \sqrt{\frac{0,7^2 + 1^2 + 4^2 + 2^2}{3}} = 2,68\% (\sigma)$$

$$U_{95} = \pm 1,96 * 2,68 \% = \pm 5,25 \% = + 0,44 / - 0,47 \text{ dB}$$

(Valid for measuring the modulation characteristics at levels at least 10 dB beyond measuring system noise level).

#### 5.1.4 Adjacent channel power

##### 5.1.4.1 The adjacent channel power meter method

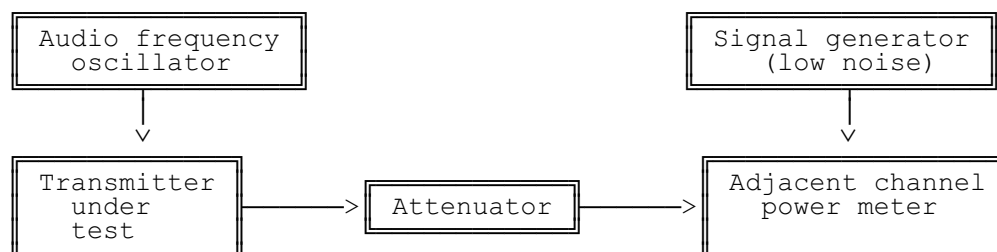


Figure 12: Measurement configuration

The transmitter under test is connected to an adjacent channel power meter (power measuring receiver) through a matching and attenuating network. The local oscillator signal to the adjacent channel power meter is supplied from a low noise signal generator.

The carrier power is approximately 25 Watts. The measuring result is obtained as the mean value of 20 measurements in order to characterise and reduce the random error caused by the noise. The transmitter is designed for intermittent use.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities.

It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Filter power band width uncertainty ( ± 0,2 dB (d) ) + 2,33 / - 2,28 % (r)

Relative accuracy ( ± 0,5 dB (d) ) + 5,93 / - 5,59 % (r)

Standard deviation of random error ( ± 0,11 dB (m)(c) ) ± 1,27 % (σ)

Uncertainty caused by deviation uncertainty: ( ± 30 Hz (r) )

(Dependency function: Mean = 0,05 % (p) / Hz  
 and std. dev. = 0,02 % (p) / Hz taken from table C.1)

$$\sqrt{\left(\frac{30^2}{3}\right) * (0,05^2 + 0,02^2)} = \text{(formular <2>)} = 0,93 \% (p) = 0,47 \% (\sigma)$$

Uncertainty caused by filter position:  
 Uncertainty of 6 dB point ± 75 Hz

(Dependency function: Mean = 15 dB/kHz,  
 and std. dev. = 4 dB/kHz taken from table C.1)

$$\sqrt{\left(\frac{0,075^2}{3}\right) * (15^2 + 4^2)} = \text{(formula <2>)} = 0,67 \text{ dB} = + 8,0 / - 7,4 \% (\sigma)$$

Time-duty-cycle uncertainty (Taken from table C.1):

Std. dev. = 2 % (p) = 1.0 % (σ)

As the measurement is purely relative the mismatch uncertainties and the attenuation uncertainties do not contribute to the measurement uncertainty.

$$\sigma_{t+} = \sqrt{\frac{2,33^2 + 5,93^2}{3} + 1,27^2 + 1,27^2 + 0,47^2 + 8,0^2 + 1,0^2} = 8,96 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{2,28^2 + 5,59^2}{3} + 1,27^2 + 0,47^2 + 7,40^2 + 1,0^2} = 8,42 \% (\sigma)$$

$$U_{95} = + 1,96 * 8,96 / - 1,96 * 8,42 = + 17,6 / - 16,5 \% = + 1,4 / - 1,6 \text{ dB}$$

The uncertainty figure is valid for results > - 95 dB.

5.1.4.2 The spectrum analyser method

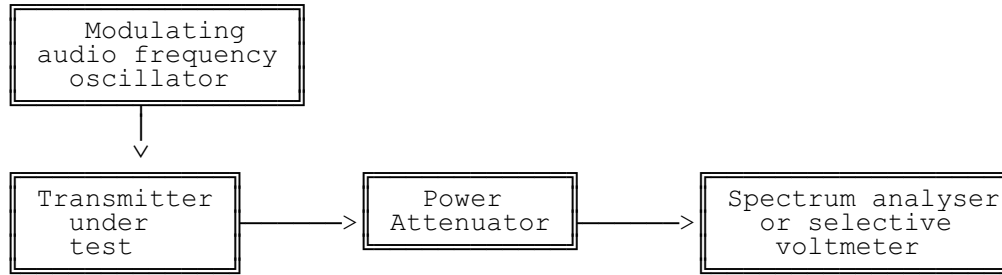


Figure 13: Measurement configuration

The transmitter under test is connected to spectrum analyser via a matching and attenuating network and the carrier is recorded as reference.

The adjacent channel power is calculated from spectrum analyser reading (9 samples) by means of Simpson's Rule.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities.

It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Reference level uncertainty:

Frequency flatness	( ± 0,6 dB (d) )	+ 7,15 / - 6,67 % (r)
Log fidelity	( ± 1,0 dB (d) )	+ 12,2 / - 10,9 % (r)
Calibrator uncertainty	( ± 0,3 dB (d) )	+ 3,51 / - 3,39 % (r)
Absolute amplitude calibration	( ± 0,6 dB (d) )	+ 7,15 / - 6,67 % (r)
Resolution bandwidth switching	( ± 0,5 dB (d) )	+ 5,93 / - 5,59 % (r)
IF gain uncertainty	( ± 1,0 dB (d) )	+ 12,2 / - 10,9 % (r)
RF gain uncertainty	( ± 0,2 dB (d) )	+ 2,33 / - 2,28 % (r)

Total reference level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{7,15^2 + 12,2^2 + 3,51^2 + 7,15^2 + 5,93^2 + 12,2^2 + 2,33^2}{3}} = 12,29 \% (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{6,67^2 + 10,9^2 + 3,39^2 + 6,67^2 + 5,59^2 + 10,9^2 + 2,28^2}{3}} = 11,17 \% (\sigma)$$

Uncertainty of calculation caused by log fidelity:  
(The circles on the figure are showing the readings)

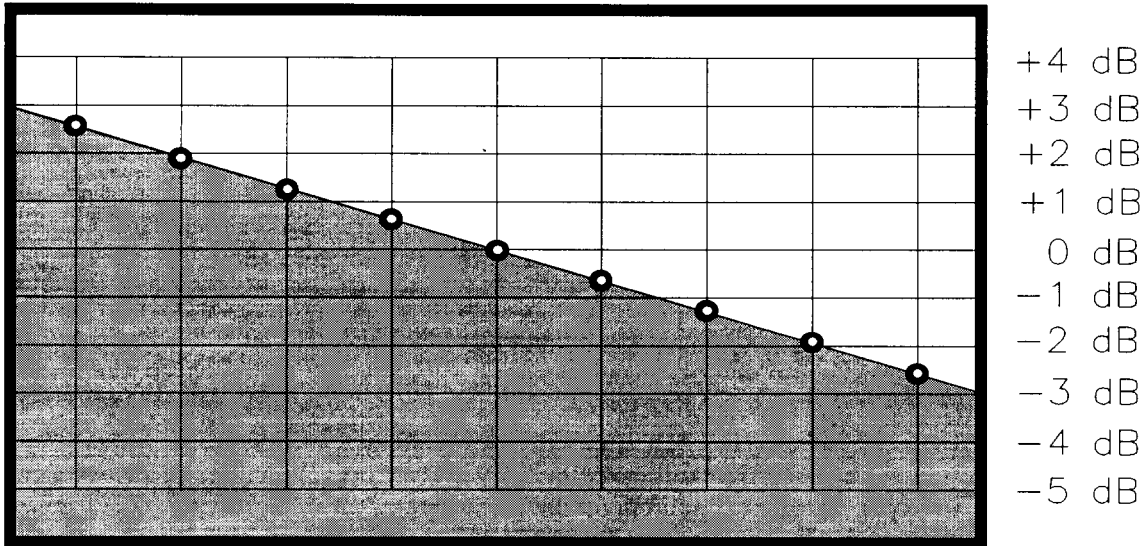


Figure 14

Reading no.	Reading	Log Fidelity	Linear error
1	+ 2,50 dB	0,250 dB	+ 2,92 / - 2,84 % (r)
2	+ 1,87 dB	0,187 dB	+ 2,18 / - 2,13 % (r)
3	+ 1,25 dB	0,125 dB	+ 1,45 / - 1,43 % (r)
4	+ 0,62 dB	0,062 dB	+ 0,72 / - 0,71 % (r)
5	0 dB	0 dB	0 % (r)
6	- 0,62 dB	0,062 dB	+ 0,72 / - 0,71 % (r)
7	- 1,25 dB	0,125 dB	+ 1,45 / - 1,43 % (r)
8	- 1,87 dB	0,187 dB	+ 2,18 / - 2,13 % (r)
9	- 2,50 dB	0,250 dB	+ 2,92 / - 2,84 % (r)

$$\sigma_{2+} = \sqrt{\frac{2,92^2 + 2,18^2 + 1,45^2 + 0,72^2 + 0,72^2 + 1,45^2 + 2,18^2 + 2,92^2}{3}} = 3,26 \% (\sigma)$$

$$\sigma_{2-} = \sqrt{\frac{2,84^2 + 2,18^2 + 1,43^2 + 0,72^2 + 0,72^2 + 0,72^2 + 1,43^2 + 2,13^2 + 2,84^2}{3}} = 3,18 \% (\sigma)$$

Frequency flatness ( ± 0,6 dB (d) ) + 7,15 / - 6,67 % (r)

Standard deviation of random error ( ± 0,11 dB (m)(c) ) ± 1,27 % (σ)

Uncertainty caused by deviation uncertainty ( ± 30 Hz (r) )

(Dependency function: Mean = 0,05 % (p) / Hz and std. dev. = 0,02 % (p) / Hz taken from table C.1)

$$\sqrt{\left(\frac{30^2}{3}\right) * (0,05^2 + 0,02^2)} = \text{(formular <2>) } = 0,93 \% (p) = 0,47 \% (\sigma)$$



Time-duty-cycle uncertainty (Taken from table C.1):

Std. dev. = 2 % (p) = 1.0 % (σ)

As the measurement is purely relative the mismatch uncertainties and the attenuation uncertainties do not contribute to the measurement uncertainty.

Total uncertainty:

$$\sigma_{t+} = \sqrt{\frac{12,29^2 + 3,26^2 + 7,15^2}{3} + 1,27^2 + 0,47^2 + 1^2} = 13,47 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{11,17^2 + 3,18^2 + 6,67^2}{3} + 1,27^2 + 0,47^2 + 1^2} = 12,35 \% (\sigma)$$

$$U_{95} = + 1,96 * 13,47 / - 1,96 * 12,35 \% = + 26,4 / - 24,2 \% \gg + 2,0 / - 2,4 \text{ dB}$$

### 5.1.5 Conducted spurious emission

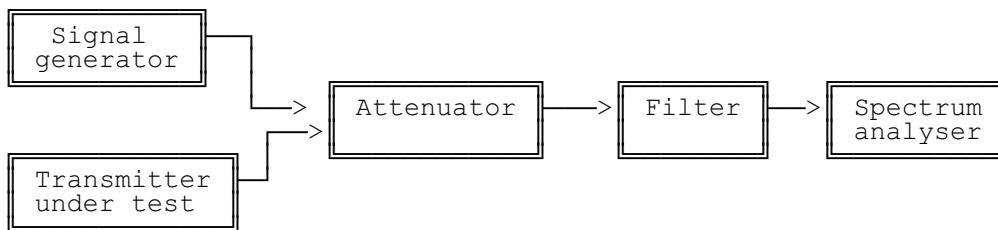


Figure 15: Measurement configuration

The transmitter is connected to a spectrum analyser through a matching and attenuating network.

The matching network includes a bandpass filter during measurements below 2,9 GHz in order to avoid overloading of the spectrum analyser. During measurements beyond 2,9 GHz the build in prescales of the spectrum analyser is active.

The individual spurious components are found and read from the analyser and corrected for attenuation and mismatch loss in the matching network, or they are substituted by means of a signal generator signal.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities.

It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Substitution method:

Power coefficient of attenuator ( ± 0,3 dB (d) ) + 3,51 / - 3,39 % (r)

Mismatch uncertainties at input:

With transmitter connected:

Transmitter reflection coefficient taken from table C.1 : Mean = 0,7 and std. dev. = 0,1  
 Network reflection coefficient 0,05 (m)  
 $m_{iu} = 0,05 * 0,7 * 100 = \pm 3,5 \%$  (u)  
 Normalised std. dev. from table C.1 =  $0,1/0,7 = 0,14$

Uncertainty correction factor from the figure 4 in subclause 4.2.2 = 1,02  
 Mismatch uncertainty =  $3,5 * 1,02/\sqrt{2} = 2,52 \%$  ( $\sigma$ )

With generator connected:

Generator reflection coefficient 0,2 (d)  
 network reflection coefficient 0,05 (m)  
 $M_{iu} = \pm 0,05 * 0,2 \%$  (c)  $\pm 1,0 \%$  (u)

Signal generator substitution  
 signal uncertainty ( $\pm 1$  dB (d) )  $+12,2/- 10,9 \%$  (r)

Uncertainty due to supply voltage:  
 Supply voltage uncertainty  $\pm 100$  mV (r)  
 Dependency function taken from table C.1:  
 Mean =  $10 \%$  (p)/V and std. dev. =  $3 \%$  (p)/V

Uncertainty:

$$\sqrt{\left(\frac{0,1^2}{3}\right) * (10,0^2 + 3,0^2)} = 0,60 \%$$
 ( $\sigma$ )(p) =  $0,30 \%$  ( $\sigma$ )

$$\sigma_{t+} = \sqrt{\frac{3,51^2 + 12,2^2}{3} + \frac{1^2}{2} + 2,52^2 + 0,3^2} = 7,79 \%$$
 ( $\sigma$ )

$$\sigma_{t-} = \sqrt{\frac{3,39^2 + 10,9^2}{3} + \frac{1^2}{2} + 2,52^2 + 0,3^2} = 7,10 \%$$
 ( $\sigma$ )

$$U_{95} = + 1,96 * 7.79 / - 1,96 * 7,10 \%$$
 =  $+ 15,3 / - 13,9 \%$  =  $+ 1,2 / - 1,3$  dB

Direct reading from spectrum analyser:

Mismatch and matching network uncertainty:

Matching and filtering network attenuation uncertainty ( $\pm 0,3$  dB (m) )  $+ 3,51/ - 3,39 \%$  (r)

Power coefficient of attenuator ( $\pm 0,3$  dB (d) )  $+ 3,51/ - 3,39 \%$  (r)

Mismatch uncertainty at input:

Network reflection coefficient 0,13 (d)  
 Transmitter reflection coefficient taken from table C.1 : Mean = 0,7 and std. dev. = 0,1  
 Network reflection coefficient 0,05 (m)  
 $m_{iu} = 0,13 * 0,7 * 100 = \pm 9,1 \%$  (u)  
 Normalised std. dev. from table C.1 =  $0,1/0,7 = 0,14$   
 Uncertainty correction factor from the figure 4 in subclause 4.2.2 = 1,02  
 Mismatch uncertainty =  $9,1 * 1,02/\sqrt{2} = 6,56 \%$  ( $\sigma$ )

Mismatch uncertainty at spectrum analyser:  
Spectrum analyser reflection coefficient 0,4  
network reflection coefficient 0,13  
 $m_{iu} = 0,13 * 0,4$

(d)  
(d)

± 5,2 % (u)

Mismatch and matching network uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(3,51^2 + 3,51^2)}{3} + \frac{5,2^2}{2} + 6,56^2} = 8,05 \% (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{(3,39^2 + 3,39^2)}{3} + \frac{5,2^2}{2} + 6,56^2} = 8,01 \% (\sigma)$$

Spectrum analyser uncertainty:

Calibration mismatch uncertainty:

Both reflection coefficients = 0,2  
 $m_{iu} = 0,2 * 0,2$

± 4,0 % (u)

300 MHz reference uncertainty (± 0,3 dB (d) )

+ 3,51 / - 3,39 % (r)

Frequency response uncertainty (± 2,5 dB (d) )

+ 33,4 / - 25,0 % (r)

Band switch uncertainty (± 0,5 dB (d) )

+ 5,93 / - 5,59 % (r)

Log fidelity (± 1,5 dB (d) )

+ 18,9 / - 15,9 % (r)

$$\sigma_{2+} = \sqrt{\frac{4,0^2}{2} + \frac{(3,51^2 + 33,4^2 + 5,93^2 + 18,9^2)}{3}} = 22,7 \% (\sigma)$$

$$\sigma_{21} = \sqrt{\frac{4,0^2}{2} + \frac{(3,39^2 + 25,0^2 + 5,59^2 + 19,9^2)}{3}} = 17,7 \% (\sigma)$$

Uncertainty due to supply voltage:

Supply voltage uncertainty ± 100 mV

(r)

Dependency function taken from table C.1:

Mean = 10 % (p)/V and std. dev. = 3 % (p)/V

Uncertainty:

$$\sqrt{\left(\frac{0,1^2}{3}\right) * (10,0^2 + 3,0^2)} = 0,60 \% (\sigma)(p) = \text{(formula <2>)} 0,30 \% (\sigma)$$

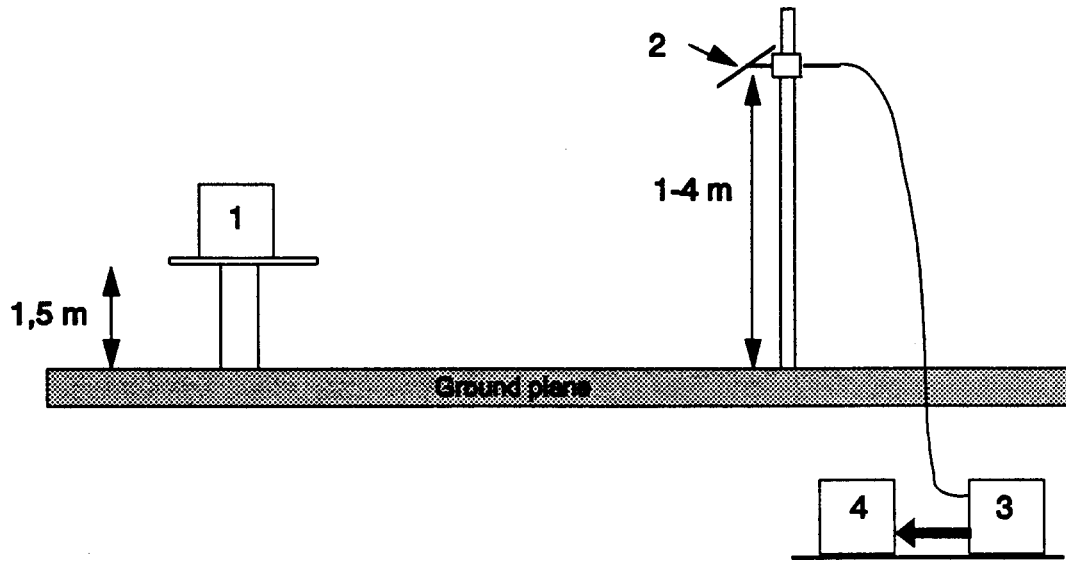
Total uncertainty:

$$\sigma_{t+} = \sqrt{8,05^2 + 22,7^2 + 0,3^2} = 24,1 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{8,01^2 + 17,7^2 + 0,3^2} = 19,4 \% (\sigma)$$

$$U_{95} = + 1,96 * 24,1 / - 1,96 * 19,4 = + 47,2 / - 38,0 \% = + 3,36 / - 4,15 \text{ dB}$$

5.1.6 Cabinet radiation



- 1) Equipment under test.
- 2) Test antenna.
- 3) High pass filter (necessary for strong fundamental Tx radiation).
- 4) Spectrum analyser or selective voltmeter.

**Figure 16: Measurement configuration**

Several test sites can be used to measure the effective radiated power of spurious emissions:

- open air test site;
- an indoor test site with absorbing material on the wall behind the test item;
- a semi anechoic chamber.
- an anechoic chamber.

Also different antennas can be used:

- 2 dipole
- horn.

The measured quantity should be determined by a substitution method. Usually the test site has been calibrated by means of the substitution method and a site attenuation curve has been recorded.

The list of error sources are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Some error sources that can contribute to the total uncertainty :

- standing wave patterns on test site;
- reflected waves;
- distance from test item to receiving antenna;
- test site attenuation uncertainty;
- disturbance caused by electronic equipment;
- cable and mismatch network attenuation uncertainty;
- antenna gain uncertainty;
- mismatch uncertainties;
- humidity;
- ambient radio frequency environment;
- log fidelity and linearity of detecting instrument;
- size and location of the test item and connected cables.

An attempt shall be made to obtain a satisfactory analytical basis for calculating the maximum acceptable accumulated measurement uncertainty for transmitter and receiver radiated spurious emissions based upon the methods of measurement recommended in standards ETS 300 086 [2], I-ETS 300 113 [3] and CEPT Recommendation T/R 24-01 Annex I to VII [4] (see Annex D).

However, all three methods are inadequately definitive over issues of ground plane characteristics, antenna separation, antenna heights, antenna types, cable positions, and most important of all, site calibration.

Further work is being carried out. The corresponding results will be incorporated in a future release of this report.

#### 5.1.7 Intermodulation attenuation

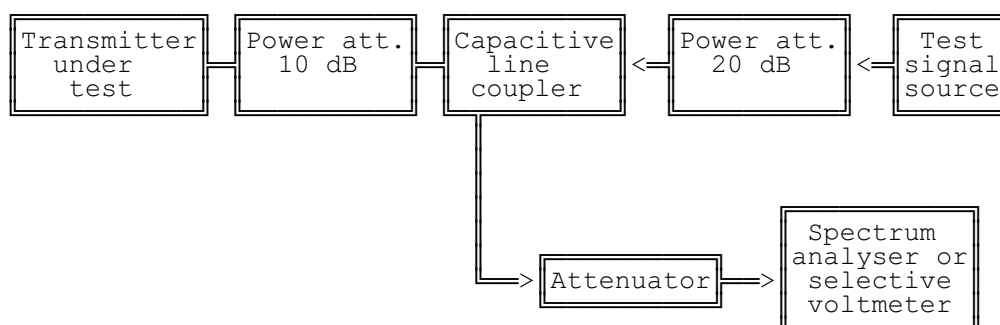


Figure 17: Measurement configuration

The transmitter is connected to a signal generator through a matching network. The network contains two power attenuators in order to prevent intermodulation in the signal generator and a directional coupler.

The level of the signal from the signal generator is measured with a power meter at the output of the matching network (the connector which during the actual measurement is connected to the transmitter output). The transmitter output is connected to a spectrum analyser via the directional coupler. The intermodulation products are compared directly by means of the spectrum analyser.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Uncertainty of the level of the unwanted signal supplied to the output connector of the receiver :

Uncertainty of transmitter carrier power  
 (taken from example 5.1.2)  $\sigma_1 = 4,34 \% (\sigma)$

Uncertainty of measuring the level of the unwanted signal:

Uncertainty of power meter  
 (taken from example 5.1.2)  $\sigma_2 = 0,78 \% (\sigma)$

Mismatch uncertainty:  
 $VSWR_g = 1,1 \rightarrow R_g = 0,048$   
 $VSWR_l = 1,15 \rightarrow R_l = 0,07$

$M_{iu} = 0,048 * 0,07 =$   $\pm 0,34 \% (c)(u)$

Total uncertainty of the adjustment of the unwanted signal:

$$\sigma_3 = \sqrt{4,34^2 + 0,78^2 + \frac{0,34^2}{2}} =$$
  $4,42 \% (\sigma)$

Mismatch uncertainty of the application of the unwanted signal:

Network reflection coefficient 0,1 (d)  
 Transmitter reflection coefficient taken from  
 table C.1 : Mean = 0,7 and std. dev. = 0,1  
 Network reflection coefficient 0,05 (m)  
 $m_{iu} = 0,1 * 0,5 * 100 = \pm 5,0 \%$  (u)  
 Normalised std. dev. from table C.1 =  $0,2/0,5 = 0,4$   
 Uncertainty correction factor from figure 4 in subclause 4.2.2 = 1,075  
 Mismatch uncertainty =  $5,0 * 1,075/\sqrt{2} =$   $3,80 \% (\sigma)$

total uncertainty of unwanted signal level:

$$\sigma_4 = \sqrt{4,42^2 + 3,8^2} =$$
  $5,83 \% (\sigma)$

Log fidelity of spectrum analyser  
 ( 1,5 dB (d) )  $+ 18,85 / - 15,86 \% (r)$

Uncertainty caused by supply voltage uncertainty is included in  $\sigma_1$

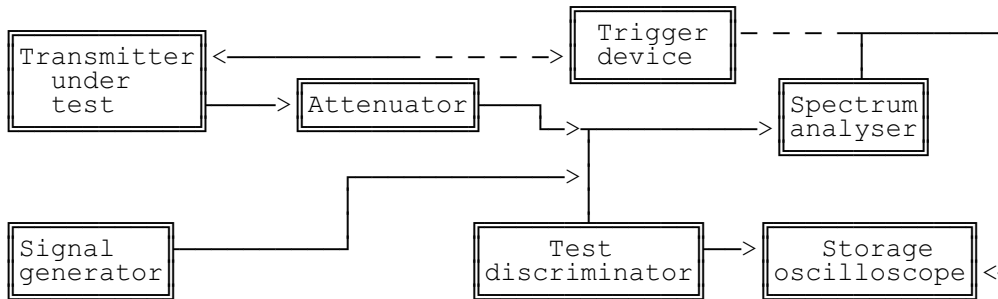
Total uncertainty:

$$\sigma_{t+} = \sqrt{5,83^2 + \frac{15,85^2}{3}} =$$
  $12,3 \% (\sigma)$

$$\sigma_{t-} = \sqrt{5,83^2 + \frac{15,86^2}{3}} =$$
  $10,9 \% (\sigma)$

$$U_{95} = + 1,96 * 12,3 / - 1,96 * 10,9 \% = + 24,2 / - 21,4 \% = + 1,9 / - 2,1 \text{ dB}$$

**5.1.8 Transmitter attack/release time**



**Figure 18**

The power level and the frequency variation as a function of time is measured by a spectrum analyser and a test discriminator connected to a storage oscilloscope.

The attack time is the time elapsed between switching on the transmitter and the moment where the carrier power level and the carrier frequency is within defined limits.

The release time is the time elapsed between switching off the transmitter and the moment where the carrier power level is lower than a defined limit.

The spectrum analyser and the discriminator are calibrated by means of the signal generator.

The nominal transmitter frequency is 1 GHz.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

**5.1.8.1 Frequency behaviour (applicable to attack time measurement)**

Signal generator frequency uncertainty (see example in subclause 5.1.1) ± 10 Hz (d)(c)

Calibration uncertainty of discriminator (including the storage oscilloscope) ± 100 Hz (r)

DC drift of discriminator ± 100 Hz (r)

Standard deviation of frequency error measurement:

$$\sigma_1 = \sqrt{(100^2 + 100^2 + 10^2)} / 3 = 81,9 \text{ Hz } (\sigma)$$

The frequency error uncertainty is then by means of the time vs. frequency error gradient (taken from table C.1) converted to time uncertainty:  
 (Table C.1 gradient: Mean = 1,0, Std. dev. = 0,3 ms/kHz)

$$\sigma_2 = \sqrt{0,0819^2 * (1,0^2 + 0,3^2)} = \text{(formular <2>)} 0,086 \text{ ms } (\sigma)$$

Oscilloscope timing uncertainty ± 1,0 ms (r)

Trigger moment uncertainty ± 1,0 ms (r)

Random uncertainty (m)(c) 0,5 ms (σ)

Total uncertainty:

$$\sigma_t = \sqrt{0,086^2 + 0,5^2 + (1^2 + 1^2) / 3} = 0,961 \text{ ms } (\sigma)$$

$$U_{95} = \pm 1,96 * 0,961 \text{ ms} = \pm 1,9 \text{ ms}$$

**5.1.8.2 Power level behaviour (applicable to attack and release time measurements)**

Spectrum analyser log fidelity ± 0,4 dB (d) = + 4,7 / - 4,5 % (r)

The power level difference uncertainty is then by means of the time/difference gradient (table C.1) converted to time uncertainty:  
 (Table C.1 gradient : Mean = 0,3, Std. dev. = 0,1 ms/ %)

$$\sigma_{1+} = \sqrt{(4,7^2 / 3) * (0,3^2 + 0,1^2)} = \text{(formular <2>)} 0,856 \text{ ms } (\sigma)$$

$$\sigma_{1-} = \sqrt{(4,5^2 / 3) * (0,3^2 + 0,1^2)} = \text{(formular <2>)} 0,822 \text{ ms } (\sigma)$$

Oscilloscope timing uncertainty ± 1,0 ms (r)

Trigger moment uncertainty ± 1,0 ms (r)

Random uncertainty (m)(c) 0,5 ms (σ)

Total uncertainty:

$$\sigma_{t+} = \sqrt{0,856^2 + (1,0^2 + 1,0^2 + 0,5^2) / 3} = 1,22 \text{ ms } (\sigma)$$

$$\sigma_{t-} = \sqrt{0,822^2 + (1,0^2 + 1,0^2 + 0,5^2) / 3} = 1,20 \text{ ms } (\sigma)$$

$$U_{95} = +1,96 * 1,22 / - 1,96 * 1,20 \text{ ms} = + 2,39 / - 2,35 \text{ ms}$$

**5.1.9 Transient behaviour of the transmitter**

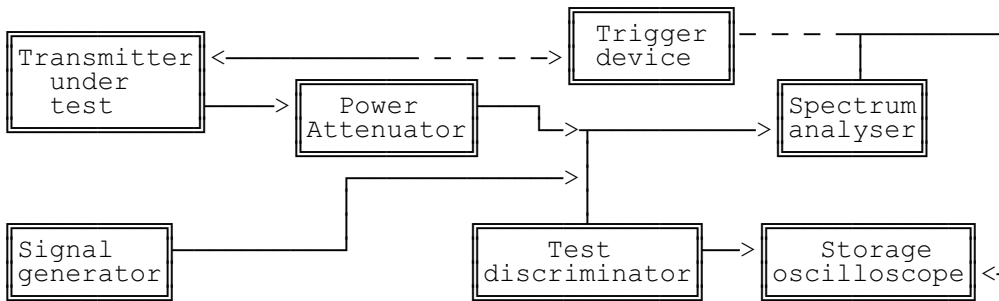


Figure 19

The power level as a function of time and the frequency error is measured by means of a spectrum analyser and a test discriminator connected to a storage oscilloscope.

The slope of the power level and the frequency error during turn on and turn off is measured.



The spectrum analyser and the discriminator are calibrated by means of the signal generator. The nominal transmitter frequency is 1 GHz.

When the power level slope is measured the spectrum analyser is in zero span mode and the sweep is adjusted so that the - 6 dB point and the - 30 dB point are at both extremes of the screen

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

### 5.1.9.1 Uncertainty in measuring frequency error

Signal generator frequency uncertainty =  $\pm 10$  Hz (d)(c)  
(see example 5.1.1)

Calibration uncertainty of discriminator  $\pm 100$  Hz (r)  
(including the storage oscilloscope)

DC drift of discriminator  $\pm 100$  Hz (r)

Standard deviation of frequency error measurement :

$$\sigma_t = \sqrt{(100^2 + 100^2 + 10^2)} / 3 = 81,9 \text{ Hz } (\sigma)$$

$$U_{95} = \pm 1,96 * 81,9 \text{ Hz} = \pm 161 \text{ Hz}$$

### 5.1.9.2 Uncertainty in measuring power level slope

(The following calculations are based on the assumption that the power level versus time is linear in logarithmic terms).

Spectrum analyser log fidelity at - 6 dB:  $\pm 0,6$  dB (d)(r)  
This is converted to time uncertainty:  $\pm 0,6/(-6+30)$  %  $\pm 2,5$  % (c)(r)

Spectrum analyser log fidelity at - 30 dB:  $\pm 1,5$  dB (d)(r)  
This is converted to time uncertainty:  $\pm 1,5/(-6+30)$  %  $\pm 6,25$  % (c)(r)

Time measurement uncertainty (counts twice)  $\pm 2$  % (r) of full screen  $\pm 2$  % (d)(r)

Random uncertainty (m) 1 % ( $\sigma$ )

Total uncertainty:

$$\sigma_{t+} = \sqrt{\frac{(2,5^2 + 6,25^2 + 2 * 2^2)}{3} + 1^2} = 4,33 \text{ % } (\sigma)$$

$$U_{95} = \pm 1,96 * 4,33 \text{ %} = \pm 8,5 \text{ %}$$

5.2 Receiver measurements

5.2.1 Maximum usable sensitivity

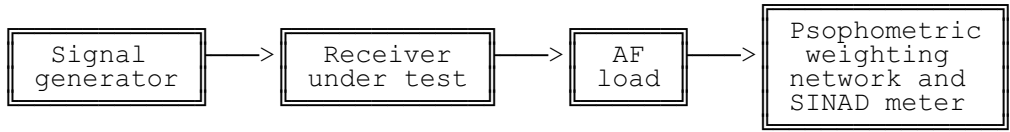


Figure 20: Measurement configuration

The signal generator is connected to the antenna connector of the receiver under test through a matching network.

The low frequency output of the receiver is suitably terminated and fed to a psophometric filter connected to a SINAD meter.

The signal generator signal is modulated with normal modulation.

The level is decreased until 20 dB SINAD as read from the SINAD meter obtained.

The result is the signal generator level corrected for mismatch losses and attenuation of matching network.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

RF level uncertainty:

Signal generator level uncertainty ( $\pm 1$  dB (d) ) + 12,2 / - 10,9 % (r)

Mismatch uncertainties at the antenna connector of the receiver:  
 ( $V_{SWR_{att}} 1,2 \rightarrow R_l = 0,091$  and  $R_g$  of the receiver under test taken from table C.1:

Mean = 0,2 std. dev. = 0,05) (u) (c) (formula <8>)

$M_{iu} = 0,091 * 0,2 * 100 \% = \pm 1,82 \%$   
 Normalised std. dev. of  $R_g = 0,05/0,2 = 0,25$   
 Correction factor (taken from figure 4 in subclause 4.2.2) = 1,03

Std. dev. of mismatch uncertainty at the antenna connector 1,33 % ( $\sigma$ )  
 $= 1,03 * 1,82/\sqrt{2} =$  (formula <9>)

Uncertainty of attenuation in cable  $\pm 1,2$  % (c) ( $\sigma$ )

Total level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{12,2^2}{3} + 1,33^2 + 1,2^2} = 7,26 \% (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{10,9^2}{3} + 1,33^2 + 1,2^2} = 6,54 \% (\sigma)$$

SINAD measurement uncertainty:

SINAD meter uncertainty ( $\pm 1$  dB (d)) + 12,2/ - 10,9 % (r)

Deviation uncertainty  $\pm 5,3$  % (d) (r)

Total SINAD uncertainty:

$$\sigma_{2+} = \sqrt{\frac{12,2^2 + 5,3^2}{3}} = 7,68 \% (\sigma)$$

$$\sigma_{2-} = \sqrt{\frac{10,8^2 + 5,3^2}{3}} = 6,95 \% (\sigma)$$

The SINAD uncertainty is then by means of formula <2> converted to level uncertainty.

Dependency function taken from table C.1: Mean = 1,0  
Standard deviation = 0,2

$$\sigma_{3+} = \sqrt{7,68^2 * (1,0^2 + 0,2^2)} = 7,83 \% (\sigma)$$

$$\sigma_{3-} = \sqrt{6,95^2 * (1,0^2 + 0,2^2)} = 7,09 \% (\sigma)$$

Uncertainty due to uncertainty of ambient temperature : (25 °C  $\pm$  3°C):

Dependency function taken from table C.1: Mean = 2,5 % /°C  
Standard deviation = 1,2 % /°C

$$\sigma_4 = \sqrt{(3^2 / 3) * (2,5^2 + 1,2^2)} = \text{(formular <2>)} = 4,8 \% (\sigma)$$

Total uncertainty:

Random uncertainty 2,0 % ( $\sigma$ ) (m)

$$\sigma_{t+} = \sqrt{7,26^2 + 7,83^2 + 5,3^2 / 3 + 4,8^2 + 2,0^2} = 12,2 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{6,54^2 + 7,09^2 + 5,3^2 / 3 + 4,8^2 + 2,0^2} = 11,3 \% (\sigma)$$

$$U_{95} = + 1,96 * 12,2 / - 1,96 * 11,3 \% = + 24,0 / - 22,2 \% = + 1,9 / - 2,2 \text{ dB}$$

5.2.2 Amplitude characteristic

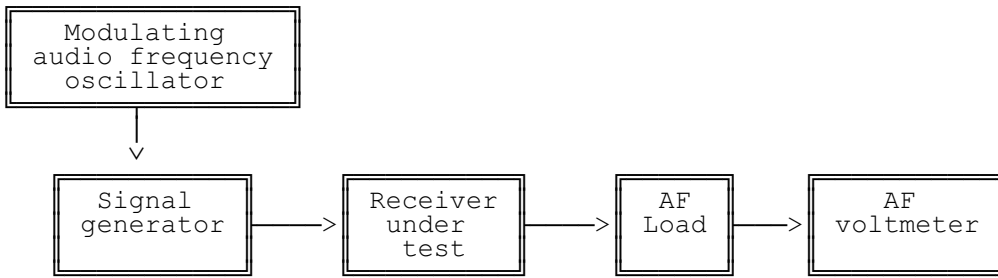


Figure 21: Measurement configuration

The receiver under test is connected to a signal generator through a matching network. The low frequency output from the receiver is suitably terminated and connected to an AC voltmeter or audio analyser.

The result is read from the AC voltmeter.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

RF level uncertainty:

Signal generator level uncertainty ( $\pm 1$  dB (d) ) + 12,2 / - 10,9 % (r)

Mismatch uncertainties at the antenna connector of the receiver:

( $VSWR_{att} 1,2 \rightarrow R_l = 0,091$  and  $R_g$  of the receiver under test taken from table C.1:

Mean = 0,2, std. dev. = 0,05)

$M_{iu} = 0,091 * 0,2 * 100 \% = \pm 1,82 \%$

(u) (c) (formula <8> )

Normalised std. dev. of  $R_g = 0,05/0,2 = 0,25$

Correction factor (taken from figure 4 in subclause 4.2.2) = 1,03

Std. dev. of mismatch uncertainty at the antenna connector =  $1,03 * 1,82/\sqrt{2} =$

1,33 % ( $\sigma$ )  
 (formula <9> )

Uncertainty of attenuation in cable

$\pm 1,2 \%$  (c) ( $\sigma$ )

Total level uncertainty:

$$\sigma_{I+} = \sqrt{\frac{12,2^2}{3} + 1,33^2 + 1,2^2} = 7,27 \% (\sigma)$$

$$\sigma_{I-} = \sqrt{\frac{10,9^2}{3} + 1,33^2 + 1,2^2} = 6,54 \% (\sigma)$$

Uncertainties caused by RF level uncertainty  $\sigma_2$ :

Dependency function taken from table C.1: Mean = 0,05 % / % level  
 Standard deviation = 0,02 % / % level

$$\sigma_{2+} = \sqrt{7,26^2 \times (0,05^2 + 0,02^2)} = 0,41 \% (\sigma)$$

$$\sigma_{2-} = \sqrt{6,54^2 \times (0,05^2 + 0,02^2)} = 0,37 \% (\sigma) \quad (\text{formular } <2>)$$

( $\sigma_2 = \sigma_{2+} = 0,41 \%$  will be used in the following calculation)

Noise variation at low RF level 2,0 % (a) ( $\sigma$ )  
 AC volt meter uncertainty  $\pm 2,0$  (d) (r)  
 (Must be allowed for twice)

The AC level is well above the measuring system noise floor.

$$\sigma_t = \sqrt{\frac{2^2 + 2^2}{3} + 2^2 + 0,41^2} = 2,61 \% (\sigma)$$

$$U_{95} = 1,96 * 2,61 = \pm 5,1 \% = + 0,43 / - 0,45 \text{ dB}$$

### 5.2.3 Two signal measurements

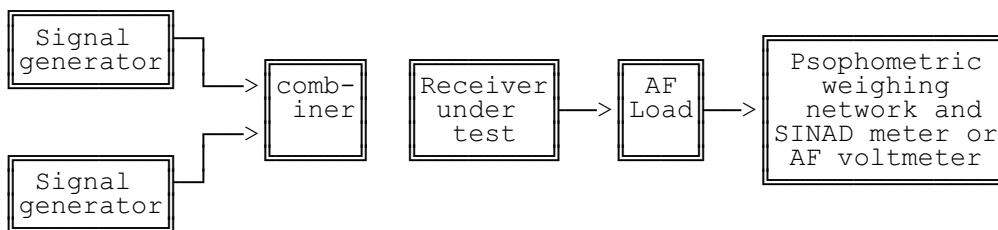


Figure 22: Measurement configuration

The receiver under test is connected to two signal generators through a combining network.

The low frequency output of the receiver is connected, suitably terminated to a SINAD meter through a psophometric filter.

The result is obtained as the difference between the signal levels of the two signal generators.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

5.2.3.1 In band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ( $\pm 1$  dB (d)) + 12,2 / - 10,9 % (r)

Generator level uncertainty (unwanted signal) ( $\pm 1$  dB (d)) + 12,2 / - 10,9 % (r)

Matching network attenuation uncertainty  $\pm 1,5$  % ( $\sigma$ )

Mismatch uncertainties:

Test signals at generator output:

Generator reflection coefficient 0,2

Matching network reflection coefficient 0,07

$M_{iu} = \pm 0,2 * 0,07$   $\pm 1,4$  % (u)

(A symmetrically matching network is assumed)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

(VSWR<sub>att</sub> 1.2  $\rightarrow R_l = 0,091$  and  $R_g$  of

the receiver under test taken from table C.1:

Mean = 0,2, std. dev. = 0,05)

$M_{iu} = 0,091 * 0,2 * 100$  % =  $\pm 1,82$  % (u) (c) (formula <8>)

Normalised std. dev. of  $R_g = 0,05/0,2 = 0,25$

Correction factor (taken from figure 4 in subclause 4.2.2) = 1,03

Std. dev. of mismatch uncertainty at the antenna connector =  $1,03 * 1,82/\sqrt{2} = 1,33$  % ( $\sigma$ ) (formula <9> )

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

- the same as for the wanted signal 1,33 % ( $\sigma$ )

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(12,2^2 + 12,2^2)}{3} + 1,5^2 + \frac{1,4^2}{2} + 1,33^2 + 1,33^2} = 10,3 \text{ % } (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{(10,9^2 + 10,9^2)}{3} + 1,5^2 + \frac{1,4^2}{2} + 1,33^2 + 1,33^2} = 9,27 \text{ % } (\sigma)$$

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\frac{12,2^2}{3} + 1,5^2 + \frac{1,4^2}{2} + 1,33^2} = 7,39 \text{ % } (\sigma)$$

$$\sigma_{2-} = \sqrt{\frac{10,9^2}{3} + 1,5^2 + \frac{1,4^2}{2} + 1,33^2} = 6,68 \text{ % } (\sigma)$$

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1: Mean = 0,5 % / % level  
 Standard deviation = 0,2 % / % level

$$\sigma_{3+} = \sqrt{7,39^2 * (0,5^2 + 0,2^2)} = 3,98 \% (\sigma)$$

$$\sigma_{3-} = \sqrt{6,68^2 * (0,5^2 + 0,2^2)} = 3,60 \% (\sigma)$$

SINAD measurement uncertainty:

SINAD meter uncertainty ( $\pm 1$  dB (d)) + 12,2 / - 10,9 % (r)

Deviation uncertainty (wanted signal)  $\pm 5,3$  % (r) (d)

Deviation uncertainty (unwanted signal)  $\pm 5,3$  (r) (d)  
= 5,3 % \* 3,0 kHz =  $\pm 159$  Hz

Deviation uncertainty of unwanted signal converted to SINAD uncertainty by means of table C.1:

Dependency function: Mean value = 0,05 % / Hz  
Standard deviation = 0,02 % / Hz

$$\sigma_4 = \sqrt{(159^2 / 3) * (0,05^2 + 0,02^2)} = \text{(formula <2>)} 4,94 \% (\sigma)$$

Total SINAD uncertainty:

$$\sigma_{5+} = \sqrt{(12,2^2 + 5,3^2) / 3 + 4,94^2} = 9,12 \% (\sigma)$$

$$\sigma_{5-} = \sqrt{(10,9^2 + 5,3^2) / 3 + 4,94^2} = 8,57 \% (\sigma)$$

The SINAD uncertainty is then by means of formula <2> converted to level uncertainty.

Dependency function taken from table C.1: Mean = 0,7  
Standard deviation = 0,2

$$\sigma_{6+} = \sqrt{9,12^2 * (0,7^2 + 0,2^2)} = 6,64 \% (\sigma)$$

$$\sigma_{6-} = \sqrt{8,57^2 * (0,7^2 + 0,2^2)} = 6,24 \% (\sigma)$$

Random uncertainty (valid for all measurements) 2,0 % ( $\sigma$ ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{10,3^2 + 7,39^2 + 3,98^2 + 6,64^2 + 2,0^2} = 15,0 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{9,27^2 + 6,68^2 + 3,60^2 + 6,24^2 + 2,0^2} = 15,0 \% (\sigma)$$

$$U_{95} = + 1,96 * 15,0 / - 1,96 * 13,7 \% = + 29,4 / - 26,1 = + 2,2 / - 2,7 \text{ dB}$$

5.2.3.2 Out of band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ( $\pm 1$  dB (d) ) + 12,2 / - 10,9 % (r)

Generator level uncertainty (unwanted signal) ( $\pm 1$  dB (d) ) + 12,2 / - 10,9 % (r)

Matching network attenuation uncertainty  $\pm 1,5$  % ( $\sigma$ )

Mismatch uncertainties:

Test signals at generator output:

Generator reflection coefficient 0,2

Matching network reflection coefficient 0,07

$M_{iu} = \pm 0,2 * 0,07$   $\pm 1,4$  % (u)

(A symmetrically matching network is assumed)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

( $VSWR_{att} 1,2 \rightarrow R_l = 0,091$  and  $R_g$  of

the receiver under test taken from table C.1:

Mean = 0,2, std. dev. = 0,05)

$M_{iu} = 0,091 * 0,2 * 100 \% = \pm 1,82 \%$  (u) (c) (formula <8>)

Normalised std. dev. of  $R_g = 0,05/0,2 = 0,25$

Correction factor (taken from figure 4 in subclause 4.2.2) = 1,03

Std. dev. of mismatch uncertainty at the antenna connector =  $1,03 * 1,82/\sqrt{2} =$  1,33 % ( $\sigma$ )  
 (formula <9>)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

( $VSWR_{att} 1,2 \rightarrow R_l = 0,091$  and  $R_g$  of

the receiver under test taken from table C.1:

Mean = 0,8, std. dev. = 0,1)

$M_{iu} = 0,091 * 0,8 * 100 \% = \pm 7,28 \%$  (u) (c) (formula <8>)

Normalised std. dev. of  $R_g = 0,1/0,8 = 0,125$

Correction factor (Taken from figure 4 in subclause 4.2.2) = 1,01

Std. dev. of mismatch uncertainty at the antenna connector =  $1,01 * 7,28/\sqrt{2} =$  5,20 % ( $\sigma$ )  
 (formula <9> )

Total level difference uncertainty:

$$\sigma_{I+} = \sqrt{(12,2^2 + 12,2^2) / 3 + 1,5^2 + 1,4^2 / 2 + 1,33^2 + 5,2^2} = 11,5 \% (\sigma)$$

$$\sigma_{I-} = \sqrt{(10,9^2 + 10,9^2) / 3 + 1,5^2 + 1,4^2 / 2 + 1,33^2 + 5,2^2} = 10,5 \% (\sigma)$$



Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{12,2^2 / 3 + 1,5^2 + 1,4^2 / 2 + 1,33^2} = 7,39 \% (\sigma)$$

$$\sigma_{2-} = \sqrt{10,9^2 / 3 + 1,5^2 + 1,4^2 / 2 + 1,33^2} = 6,68 \% (\sigma)$$

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1: Mean = 0,5 % / % level  
Standard deviation = 0,2 % / % level

$$\sigma_{3+} = \sqrt{7,39^2 * (0,5^2 + 0,2^2)} = \text{(formular <2>)} 3,98 \% (\sigma)$$

$$\sigma_{3-} = \sqrt{6,68^2 * (0,5^2 + 0,2^2)} = 3,60 \% (\sigma)$$

SINAD measurement uncertainty:

SINAD meter uncertainty ( $\pm 1$  dB (d)) + 12,2/ - 10,9 % (r)

Deviation uncertainty (wanted signal)  $\pm 5,3$  % (r) (d)

Deviation uncertainty (unwanted signal)  $\pm 5,3$  (r) (d)  
= 5,3 % \* 3,0 kHz =  $\pm 159$  Hz

Deviation uncertainty of unwanted signal converted to SINAD uncertainty by means of table C.1:

Dependency function: Mean value = 0,05 % / Hz  
Standard deviation = 0,02 % / Hz

$$\sigma_4 = \sqrt{(159^2 / 3) * (0,05^2 + 0,02^2)} = \text{(formula <2>)} 4,94 \% (\sigma)$$

Total SINAD uncertainty:

$$\sigma_{5+} = \sqrt{(12,2^2 + 5,3^2) / 3 + 4,94^2} = 9,12 \% (\sigma)$$

$$\sigma_{5-} = \sqrt{(10,9^2 + 5,3^2) / 3 + 4,94^2} = 8,57 \% (\sigma)$$

The SINAD uncertainty is then by means of formula <2> converted to level uncertainty.

Dependency function taken from table C.1: Mean = 0,7  
Standard deviation = 0,2

$$\sigma_{6+} = \sqrt{9,12^2 * (0,7^2 + 0,2^2)} = 6,64 \% (\sigma)$$

$$\sigma_{6-} = \sqrt{8,57^2 * (0,7^2 + 0,2^2)} = 6,24 \% (\sigma)$$

Random uncertainty 2,0 % ( $\sigma$ ) (m)

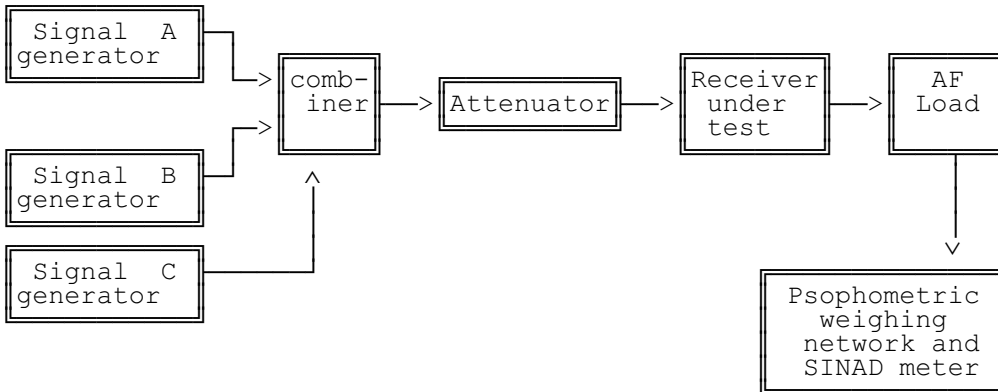
Total uncertainty:

$$\sigma_{t+} = \sqrt{11,5^2 + 7,39^2 + 3,98^2 + 6,64^2 + 2,0^2} = 15,9 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{10,5^2 + 6,68^2 + 3,60^2 + 6,64^2 + 2,0^2} = 14,5 \% (\sigma)$$

$$U_{95} = + 1,96 * 15,9 / - 1,96 * 14,5 \% = + 31,2 / - 28,4 \% = + 2,4 / - 2,9 \text{ dB}$$

**5.2.4 Intermodulation response**



**Figure 23: Measurement configuration**

The receiver under test is connected to three signal generators through a combining network which may contain isolators and attenuators.

The low frequency output of the receiver is connected to a suitable termination and a SINAD meter via a psophometric filter.

The result is the signal level of the unwanted signal generators.

All signal generator levels are corrected for combining network attenuation and mismatch loss.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Error caused by uncertainty of the level of the unwanted signals:

Signal generator A level uncertainty ( $\pm 1 \text{ dB (d)}$ ) + 12,2 / - 10,9 % (r)

Mismatch uncertainty, generator A:

Generator reflection coefficient 0,2

Matching network reflection coefficient 0,07

$$M_{iu} = \pm 0,2 * 0,07 \quad \pm 1,4 \% (u)$$

$$\text{Matching network attenuation uncertainty (Generator A to EUT)} \quad \pm 1,5 \% (\sigma) (c)$$

Total level uncertainty, generator A:

$$\sigma_{A+} = \sqrt{12,2^2 / 3 + 1,5^2 + 1,4^2 / 2} = \quad 7,27 \% (\sigma)$$

$$\sigma_{A-} = \sqrt{10,9^2 / 3 + 1,5^2 + 1,4^2 / 2} = \quad 6,54 \% (\sigma)$$

$$\text{Signal generator B level uncertainty } (\pm \text{ dB } (d)) \quad + 12,2 / - 10,9 \% (r)$$

Mismatch uncertainty, generator B:

Generator reflection coefficient 0,2

Matching network reflection coefficient 0,07

$$M_{iu} = \pm 0,2 * 0,07 \quad \pm 1,4 \% (u)$$

$$\text{Matching network attenuation uncertainty (Generator B to EUT)} \quad \pm 1,5 \% (\sigma) (c)$$

Uncertainty caused by unwanted signal levels:

Total level uncertainty, generator B:

$$\sigma_{B+} = \sqrt{12,2^2 / 3 + 1,5^2 + 1,4^2 / 2} = \quad 7,26 \% (\sigma)$$

$$\sigma_{B-} = \sqrt{10,9^2 / 3 + 1,5^2 + 1,4^2 / 2} = \quad 6,54 \% (\sigma)$$

Uncertainty due to unwanted signal level uncertainty:

$$\sigma_{1+} = \sqrt{(2 * 7,27 / 3)^2 + (7,27 / 3)^2} = \quad 5,42 \% (\sigma)$$

$$\sigma_{1-} = \sqrt{(2 * 6,54 / 3)^2 + (6,54 / 3)^2} = \quad (\text{formular } <13>) = \quad 4,87 \% (\sigma)$$

Error caused by uncertainty of the level of the wanted signal:

$$\text{Uncertainty of wanted signal generator level (generator C) } (\pm \text{ dB } (d)) \quad + 12,2 / - 10,9 \% (r)$$

$$\text{Uncertainty of attenuation in matching network} \quad \pm 1,5 \% (\sigma) (c)$$

Mismatching uncertainty at generator:

Generator reflection coefficient = 0,2 (d)

Matching network reflection coefficient = 0,07 (m)

$$M_{iu} = 0,2 * 0,07 \% \quad \pm 1,4 \% (u)$$

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

( $VSWR_{att} 1,2 \rightarrow R_l = 0,091$  and  $R_g$  of the receiver under test taken from table C.1:

Mean = 0,2, std. dev. = 0,05)

$$M_{iu} = 0,091 * 0,2 * 100 \% = \pm 1,82 \%$$

(u) (c) (formula <8>)

Normalised std. dev. of  $R_g = 0,05/0,2 = 0,25$

Correction factor (taken from figure 4 in subclause 4.2.2) = 1,03

Std. dev. of mismatch uncertainty at the antenna

$$\text{connector} = 1,03 * 1,82/\sqrt{2} =$$

(formula <9> )

1,33 % ( $\sigma$ )

Total uncertainty of wanted signal:

$$\sigma_{c+} = \sqrt{12,2^2 / 3 + 1,5^2 + 1,4^2 / 2 + 1,33^2} =$$

7,39 % ( $\sigma$ )

$$\sigma_{c-} = \sqrt{10,9^2 / 3 + 1,5^2 + 1,4^2 / 2 + 1,33^2} =$$

6,68 % ( $\sigma$ )

Uncertainty due to wanted signal level uncertainty:

a) Uncertainty due to intermodulation:

$$\sigma_{2a+} = 2 * 7,39/3 =$$

4,93 % ( $\sigma$ )

$$\sigma_{2a-} = 2 * 6,68/3 =$$

(formula <14>)

4,45 % ( $\sigma$ )

b) Uncertainty due to change in capture ratio as function of wanted signal level :

Dependency function taken from table C.1:

Mean = 0,1, Std. deviation = 0,03

$$\sigma_{2b} = \sqrt{7,39^2 * (0,1^2 + 0,03^2)} =$$

0,77 % ( $\sigma$ )

$$\sigma_{2b-} = \sqrt{6,68^2 * (0,1^2 + 0,03^2)} =$$

(formula <2>)

0,70 % ( $\sigma$ )

$$\sigma_{2+} = \sqrt{4,93^2 + 0,77^2} =$$

4,99 % ( $\sigma$ )

$$\sigma_{2-} = \sqrt{4,45^2 + 0,70^2} =$$

4,51 % ( $\sigma$ )

Uncertainty of SINAD measurement:

SINAD meter uncertainty ( $\pm 1$  dB (d) )

+ 12,2 / - 10,9 % (r)

Test signal deviation uncertainty (Must be allowed for twice)

$\pm 5$  % (r)

$$\sigma_{3+} = \sqrt{(5,0^2 + 5,0^2 + 12,2^2) / 3} =$$

8,14 % ( $\sigma$ )

$$\sigma_{3-} = \sqrt{(5,0^2 + 5,0^2 + 10,9^2) / 3} =$$

7,50 % ( $\sigma$ )

The SINAD uncertainty is then by means of formula <2> converted to level uncertainty :  
 Dependency function taken from table C.1: Mean = 0,5  
 Standard deviation = 0,1

SINAD uncertainty converted to (unwanted) level uncertainty:

$$\sigma_{4+} = \sqrt{8,14^2 * (0,5^2 + 0,1^2)} = 4,15 \% (\sigma)$$

$$\sigma_{4-} = \sqrt{7,50^2 * (0,5^2 + 0,1^2)} = 3,82 \% (\sigma) \quad (\text{formular } <2>)$$

$$\text{Standard deviation of random uncertainty} = 2,4 \% (m) (\sigma)$$

Total uncertainty:

$$\sigma_{t+} = \sqrt{5,42^2 + 4,99^2 + 4,15^2 + 2,4^2} = 8,79 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{4,87^2 + 4,51^2 + 3,82^2 + 2,4^2} = 8,02 \% (\sigma)$$

$$U_{95} = + 1,96 * 8,79 / - 1,96 * 8,02 \% = + 17,2 / - 15,7 \% = + 1,4 / - 1,5 \text{ dB}$$

### 5.2.5 Conducted spurious emission

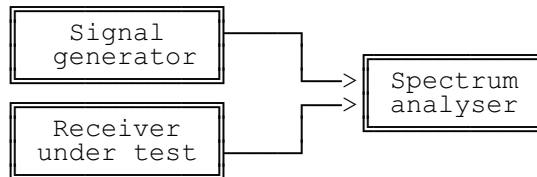


Figure 24: Measurement configuration

The receiver is connected to a spectrum analyser.

The individual spurious components are found and read from the analyser and corrected for attenuation and mismatch loss in the matching network, or they are substituted by a signal generator signal.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

Substitution method:

Mismatch uncertainties at input:

a) With receiver connected:

Receiver reflection coefficient taken from  
 Table C.1 : Mean = 0,7 and std. dev. = 0,1  
 Spectrum analyser reflection coefficient 0,15 (d)  
 $M_{iu} = 0,15 * 0,7 * 100 = \pm 10,5 \% (u)$   
 Normalised std. dev. from table C.1 =  $0,1/0,7 = 0,14$

Uncertainty correction factor from figure 4 in  
 subclause 4.2.2 = 1,02  
 Mismatch uncertainty =  $10,5 * 1,02/\sqrt{2} = 7,56 \% (\sigma)$

b) With generator connected:

Generator reflection coefficient 0,2 (d)  
 Spectrum analyser reflection coefficient 0,15 (d)  
 $M_{iu} = \pm 0,15 * 0,2 \% (c) \pm 3,0 \% (u)$

Signal generator substitution  
 Signal uncertainty ( $\pm 1$  dB (d) ) + 12,2 / - 10,9 % (r)

Uncertainty due to supply voltage:  
 Supply voltage uncertainty  $\pm 100$  mV (r)  
 Dependency function taken from table C.1:  
 Mean = 10 % (p)/V and std. dev. = 3% (p)/V  
 Uncertainty =  $\sqrt{(0,1^2/3) * (10,0^2 + 3,0^2)} = 0,60 \% (\sigma) (p) = 0,3 \% (\sigma)$   
 (formula <2>)

$$\sigma_{y+} = \sqrt{\frac{12,2^2}{3} + \frac{3^2}{2} + 7,56^2 + 0,3^2} = 10,6 \% (\sigma)$$

$$\sigma_{y-} = \sqrt{\frac{10,9^2}{3} + \frac{3^2}{2} + 7,56^2 + 0,3^2} = 10,1 \% (\sigma)$$

$$U_{95} = + 1,96 * 10,6 / - 1,96 * 10,1 \% = + 20,8 / - 19,8 \% = + 1,6 / - 1,9 \text{ dB}$$

Direct reading from spectrum analyser:

Mismatch uncertainties at input:  
 With receiver connected:  
 Receiver reflection coefficient taken from  
 table C.1 : Mean = 0,7 and std. dev. = 0,1  
 Spectrum analyser reflection coefficient 0,15 (d)  
 $M_{iu} = 0,15 * 0,7 * 100 = \pm 10,5 \% (u)$   
 Normalised std. dev. from table C.1 =  $0,1/0,7 = 0,14$

Uncertainty correction factor from figure 4 in  
 subclause 4.2.2 = 1,02  
 Mismatch uncertainty =  $10,5 * 1,02/\sqrt{2} = 7,56 \% (\sigma)$

Spectrum analyser uncertainty:

Calibration mismatch uncertainty:

Both reflection coefficients = 0,2

$$M_{iu} = 0,2 * 0,2$$

$$\pm 4,0 \% (u)$$

300 MHz reference uncertainty ( $\pm 0,3$  dB (d))

$$+ 3,51 / - 3,39 \% (r)$$

Frequency response uncertainty ( $\pm 2,5$  dB (d))

$$+ 33,4 / - 25,0 \% (r)$$

Band switch uncertainty ( $\pm 0,5$  dB (d))

$$+ 5,93 / - 5,59 \% (r)$$

Log fidelity ( $\pm 1,5$  dB (d))

$$+ 18,9 / - 15,9 \% (r)$$

Uncertainty due to supply voltage:

Supply voltage uncertainty  $\pm 100$  mV (r)

Dependency function taken from table C.1:

Mean = 10 % (p)/V and std. dev. = 3 % (p)/V

$$\text{Uncertainty} = \sqrt{(0,1^2 / 3) * (10,2^2 + 3,0^2)} = 0,60\% (\sigma) (p) \quad 0,30 \% (\sigma)$$

(formula <2>)

total uncertainty:

$$\sigma_{t+} = \sqrt{\frac{(3,51^2 + 33,4^2 + 5,93^2 + 18,9^2)}{3} + \frac{4,0^2}{2} + 0,3^2 + 7,56^2} = 23,9 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(3,39^2 + 25,0^2 + 5,59^2 + 15,9^2)}{3} + \frac{4,0^2}{2} + 0,3^2 + 7,56^2} = 19,3 \% (\sigma)$$

$$U_{95} = + 1,96 * 23,9 / - 1,96 * 19,3 \% = + 46,8 / - 37,8 \% = + 3,34 / - 4,12 \text{ dB}$$

## 5.2.6 Cabinet radiation

See subclause 5.1.6.

5.3 Duplex operation measurements

5.3.1 Receiver desensitisation

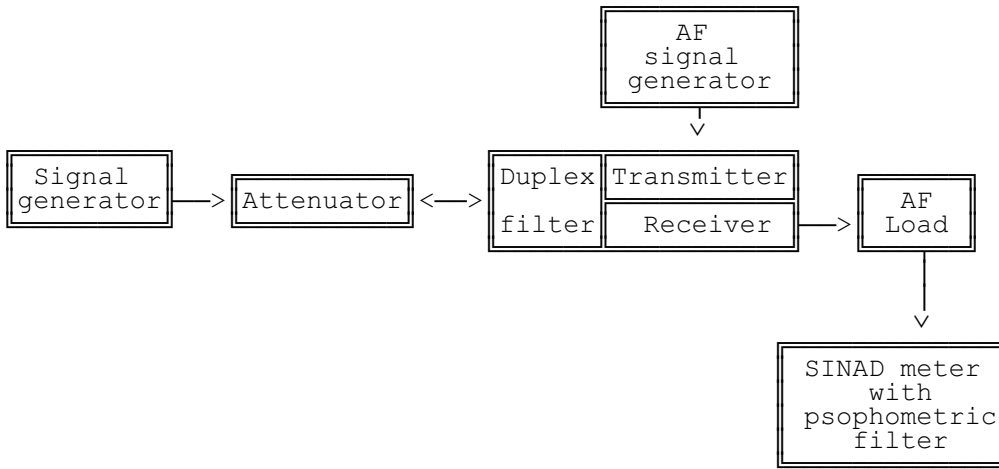


Figure 25: Measurement configuration for equipment with duplex filter

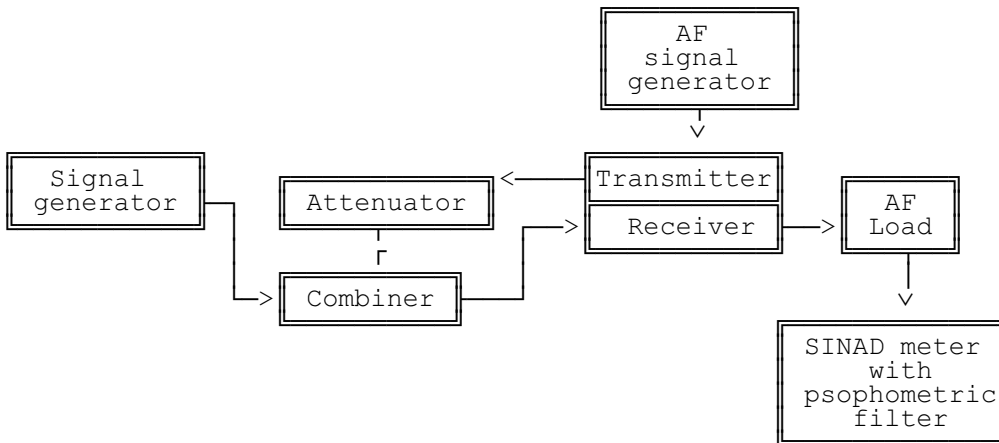


Figure 26: Measurement configuration for equipment without duplex filter

The radio under test is connected to a signal generator via a matching and attenuating network which may contain an isolator or circulator.

The low frequency output is connected to an AF load and a SINAD meter through a psophometric filter.

The sensitivity is measured twice : once with the transmitter in stand by and once with the transmitter activated.

The result is the difference between the two signal levels of the signal generator.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.



Measurement uncertainty:

Power behaviour of the attenuator in matching network:

Power coefficient 0,001 dB/dB \* Watt  
10 dB attenuator 0,001 \* 25 W \* 10 dB = (± 0,25 dB (d)) + 2,92 / - 2,84 % (r)

Linearity of signal generator (± 0,3 dB (d)) + 3,51 / - 3,39 % (r)

Mismatch uncertainties at the antenna connector of the receiver:  
(VSWR<sub>att</sub> 1,2 → R<sub>l</sub> = 0,091 and R<sub>g</sub> of the receiver under test taken from table C.1:

Mean = 0,2, std. dev. = 0,05)

M<sub>iu</sub> = 0,091 \* 0,2 \* 100 % = ± 1,82 %

(u) (c) (formula <8>)

Normalised std. dev. of R<sub>g</sub> = 0,05/0,2 = 0,25

Correction factor (taken from the figure 4 in subclause 4.2.2) = 1,03

Std. dev. of mismatch uncertainty at

the antenna connector = 1,03 \* 1,82/√2 = 1,33 % (σ)  
(formula <9> )

(Counts twice under the assumption that the reflection coefficient changes when the transmitter is activated).

Total signal level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{2,92^2 + 3,51^2}{3} + 2 * 1,33^2} = 3,24 \% (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{2,84^2 + 3,39^2}{3} + 2 * 1,33^2} = 3,17 \% (\sigma)$$

SINAD measurement uncertainty:

(The systematic SINAD uncertainty is outbalanced)

Uncertainty due to uncertainty of ambient temperature : (25°C ± 3°C):

Dependency function taken from table C.1: Mean = 2,5 %/°C  
Standard deviation = 1,2 %/°C

$$\sigma_2 = \sqrt{(3^2 / 3) * (2,5^2 + 1,2^2)} = \text{(formular <2>)} = 4,8 \% (\sigma)$$

Random uncertainty 2,5 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{3,24^2 + 2,5^2 + 4,8^2} = 6,31 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{3,17^2 + 2,5^2 + 4,8^2} = 6,27 \% (\sigma)$$

$$U_{95} = + 1,96 * 6,31 / - 1,96 * 6,27 \% = + 12,37 / - 12,29 \% = + 1,01 / - 1,14 \text{ dB}$$

5.3.2 Receiver spurious response rejection.

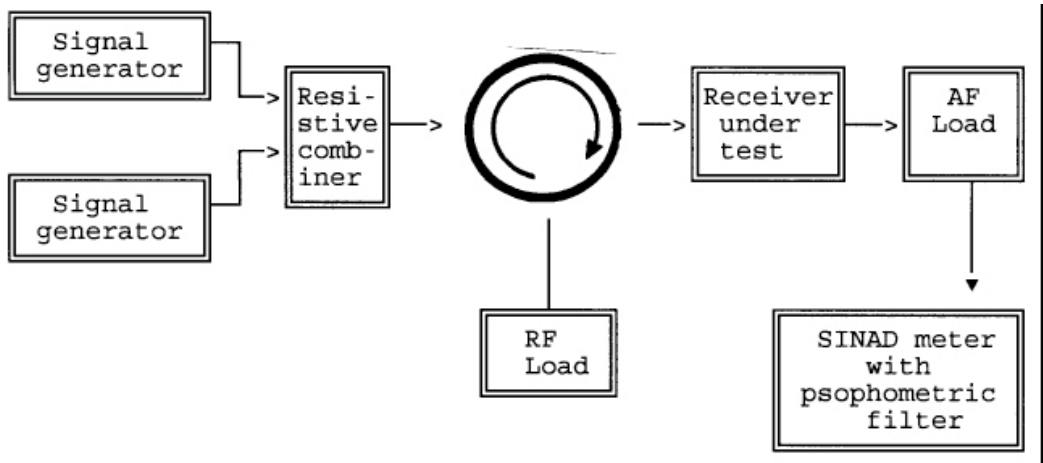


Figure 27: Measurement configuration for spurious response at in band frequencies

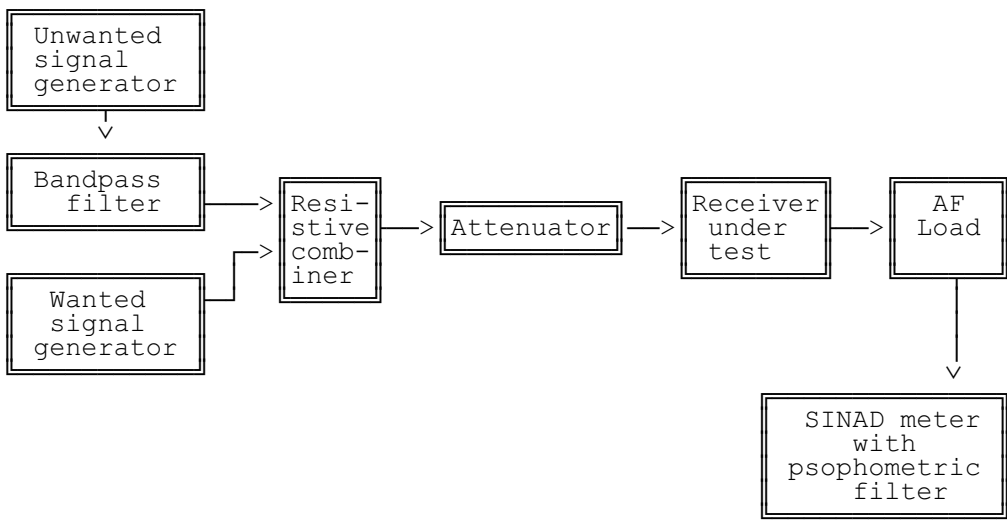


Figure 28: Measurement configuration for spurious response at out of band frequencies

The radio under test is connected to two signal generators via a combining and attenuating network.

The low frequency output of the receiver is connected to a suitable termination and a SINAD meter via a psophometric filter.

The result is the signal level of the unwanted signal generator. Both signal generator levels are corrected for combining network attenuation and mismatch loss.

The test configuration, the list of error sources and the calculations are examples only may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Measurement uncertainty:

The errors contributing to the total measurement uncertainty are the same as the example in subclause 5.2.3 with one additional error: the power behaviour of the matching network.

Uncertainty caused by power influence on matching network:

(At a carrier power of 25 W).

0,001 dB/dB<sub>Att</sub> \* W (10 dB attenuator, 25 W):

$$0,001 * 25 * 10 \text{ dB} = \pm 0,25 \text{ dB} = + 2,92 / - 2,84 \% (\text{r})$$

Total uncertainty for in band measurements:

$$\text{Standard deviation taken from example 5.2.3} = + 15,0 / - 13,7 \% (\sigma)$$

$$\sigma_{t+} = \sqrt{\frac{15,0^2 + 2,92^2}{3}} = 15,1 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{13,7^2 + 2,84^2}{3}} = 13,8 \% (\sigma)$$

$$U_{95} = + 1,96 * 15,1 / - 1,96 * 13,8 \% = + 29,6 / - 27,0 \% = + 2,3 / - 2,7 \text{ dB}$$

Total uncertainty for out of band measurements:

$$\text{Standard deviation taken from example 5.2.3} = + 15,9 / - 14,5 \% (\sigma)$$

$$\sigma_{t+} = \sqrt{\frac{15,9^2 + 2,92^2}{3}} = 16,0 \% (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{14,5^2 + 2,84^2}{3}} = 14,6 \% (\sigma)$$

$$U_{95} = + 1,96 * 16,0 / - 1,96 * 14,6 \% = + 31,3 / - 28,6 \% = + 2,4 / - 2,9 \text{ dB}$$

## Annex A

The accumulated measurement uncertainties of the test system in use for the parameters to be measured should not exceed those given in table A.1. This is in order to insure that the measurements remain within an acceptable quality.

**Table A.1: Recommended maximum acceptable uncertainties.**

RF Frequency	$\pm 1 \times 10^{-7}$
RF Power (valid to 100 W)	$\pm 0,75$ dB
Maximum Frequency Deviation	
- within 300 Hz and 6 kHz of audio frequency	$\pm 5$ %
- within 6 kHz and 25 kHz of audio frequency	$\pm 3$ dB
Deviation Limitation	$\pm 5$ %
Audio Frequency Response of Transmitters	$\pm 0,5$ dB
Adjacent Channel Power	$\pm 3$ dB
Conducted Emissions of Transmitters	$\pm 4$ dB
Transmitter Distortion	$\pm 2$ %
Transmitter Residual Modulation	$\pm 2$ dB
Audio Output Power	$\pm 0,5$ dB
Audio Frequency Response of Receivers	$\pm 1$ dB
Amplitude Characteristics of Receiver Limiter	$\pm 1,5$ dB
Hum and Noise	$\pm 2$ dB
Receiver Distortion	$\pm 2$ %
Sensitivity for 20 dB SINAD	$\pm 3$ dB
Conducted Emissions of Receivers	$\pm 4$ dB
Two-Signal Measurements (stop band)	$\pm 4$ dB
Three-Signal Measurements	$\pm 3$ dB
Radiated Emissions of Transmitters	$\pm 6$ dB
Radiated Emissions of Receivers	$\pm 6$ dB
Transmitter Attack and Release Time	$\pm 4$ ms
Transmitter Transient Frequency	$\pm 250$ Hz
Transmitter Intermodulation	$\pm 5$ dB
Receiver Desensitization (Duplex op.)	$\pm 0,5$ dB
Test methods according to relevant ETSS	
The uncertainty figures are valid for a confidence level of 95 %	

## **Annex B: Interpretation of the measurement results**

The interpretation of the results recorded in a test report for the measurements described in the standard should be as follows:

The measurement value related to the corresponding limit should be used to decide whether an equipment meets the requirements of the relevant standards.

The measurement uncertainty value for the measurement of each parameter should be included in the test reports.

The recorded value for the measurement uncertainty should be, for each measurement, equal to or lower than the figures in the appropriate table (table of "maximum acceptable measurement uncertainties" of the appropriate ETS).

NOTE: This procedure is recommended until superseded by other appropriate publications of ETSI.

**Annex C**

Table C.1 is a list of influence quantity dependency functions and uncertainties that are dependant on the equipment under test only. They are nevertheless necessary for the calculation of the absolute measurement uncertainty.

The table contains three types of parameters :

- reflection coefficients for the calculation of mismatch uncertainty.
- dependency factors for the conversion from influence quantity uncertainty to uncertainty related to the measurand.
- additional uncertainty caused by influence quantities.

The test laboratory making the measurements can by means of additional measurements estimate its own influence quantity dependencies, but if this is not carried out the values stated in table C.1 shall be used.

Table C.1 is based on measurements on a variety of equipment types. Each dependency is expressed as a mean value with a standard deviation reflecting the variation from one EUT to another. Some dependencies related to the general test conditions (supply voltage, ambient temperature, etc.) theoretically influence the results of all the measurements, but in some of the measurements they are so small that they are considered to be negligible.

The table is divided into sub tables relating to each measurement example of Clause 5.

The corresponding subclause numbers are shown in brackets.

**Table C.1: EUT-dependency functions and uncertainties.**

	Mean	Std. dev.
Frequency Error (see subclause 5.1.1) Temperature dependency Time-duty cycle error	0,02 0	0,01 ppm / °C 50 Hz
Carrier Power (see subclause 5.1.2) Reflection coefficient Temperature dependency Time-duty cycle error Supply voltage dependency	0,5 1 0 10	0,2 0,3 Watts / °C 2 ‰ (p) 3 ‰ (p) / V
Frequency Deviation (see subclause 5.1.3) Temperature dependency	0,02	0,01 ppm / °C
Adjacent Channel Power (see subclause 5.1.4) Deviation dependency Filter position dependency Time-duty cycle error	0,05 15 0	0,02 ‰ (p) / Hz 4 dB / kHz 2 ‰ (p)
Conducted Spurious Emissions (see subclause 5.1.5) Reflection coefficient Time-duty cycle error Supply voltage dependency	0,7 0 10	0,1 2 ‰ (p) 3 ‰ (p) / V

**continued**

Table C.1 (concluded)

	Mean	Std. dev.
Intermodulation Attenuation (see subclause 5.1.7)		
Reflection coefficient	0,5	0,2
Time-duty cycle error	0	2 % (p)
Supply voltage dependency	10	3 % (p) / V
Transmitter attack/release time (see subclause 5.1.8)		
Time/frequency error gradient	1,0	0,3 ms / kHz
Time/power level gradient	0,3	0,1 ms / %
Maximum Usable Sensitivity (see subclause 5.2.1)		
Reflection coefficient	0,2	0,05
Temperature dependency	2,5	1,2 % / °C
Noise gradient	1,0	0,2 % level / % SINAD
Amplitude Characteristic (see subclause 5.2.2)		
Reflection coefficient	0,2	0,05
RF level dependency	0,05	0,02 % / % level
Two signal measurements (see subclause 5.2.3)		
Reflection coefficient (in band)	0,2	0,05
Reflection coefficient (out of band)	0,8	0,1
Noise gradient	0,7	0,2 % level / % SINAD
Deviation dependency	0,05	0,02 / Hz
Absolute RF level dependency	0,5	0,2 % / % level
Intermodulation Response (see subclause 5.2.4)		
Reflection coefficient	0,2	0,05
Noise gradient (unwanted signal)	0,5	0,1 % level / % SINAD
Deviation dependency	0,05	0,02 / Hz
Capture ratio dependency	0,1	0,03 % / % level
Conducted Spurious Emission (see subclause 5.2.5)		
Reflection coefficient	0,7	0,1
Supply voltage dependency	10	3 % / V
Maximum Usable Sensitivity (see subclause 5.3.1)		
Reflection coefficient	0,2	0,05
Temperature dependency	2,5	1,2 % / °C
Noise gradient	1,0	0,2 % level / % SINAD
Spurious Response Rejection (see subclause 5.3.2)		
Reflection coefficient (pass band)	0,2	0,05
Reflection coefficient (stop band)	0,8	0,1
Noise gradient	0,7	0,2 % level / % SINAD
Deviation dependency	0,05	0,02 / Hz
Absolute RF level dependency	0,5	0,2 % / % level

## Annex D: References

Within this ETR the following references apply:

- [1] ETR 027: "Methods of measurement for private mobile radio equipment".
- [2] ETS 300 086: "Radio Equipment and Systems (RES); Land mobile service Technical characteristics and test conditions for radio equipment with an internal or external RF connector intended primarily for analogue speech".
- [3] I-ETS 300 113: "Radio Equipment and Systems (RES); Land mobile service Technical characteristics and test conditions for non-speech and combined analogue speech/non-speech equipment with an internal or external antenna connector intended for the transmission of data".
- [4] CEPT Recommendation T/R 24-01: "Specifications for equipments for use in the Land Mobile Service".



## Annex E: Bibliography

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Statens Tekniske Provenaevn (STP) : "Maleusikkerhed generelt" (The Danish Accreditation Committee (STP) : "Measurement uncertainty generally"). June 1988 (Danish)

Per Bennich, Institut for Produktudvikling : "Usikkerhed pa maleresultater" (Per Bennich, Institute for Product Development : "Uncertainty of measured results"). October 1988. (Danish)

## History

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